SCIENCE READERS

# HUGHES'S
# SCIENCE READERS.

EDITED BY

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NO. 3.

FOR

**STANDARD V.**

BY A. NEWSHOLME, M D.

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*PROFUSELY ILLUSTRATED.*

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LONDON: JOSEPH HUGHES,
PILGRIM STREET, LUDGATE HILL, E.C.
1884.

# PREFACE.

An attempt has been made in this Science Reader to give the broad principles and facts of Elementary Physics and Chemistry without overloading the subject with details.

As the book is not intended to be a complete scientific manual on the subjects of which it treats, but a reading book for Elementary Scholars in Standard V., the matter has been given as untechnically as possible; and wherever feasible, the subject has been treated experimentally, the author being convinced that only by seeing, and, where possible, actually performing the experiments described, can a rational and permanent knowledge of Physics and Chemistry be obtained.

The Vocabulary at the end of the book, defining all difficult terms used, will, it is hoped, make the book more useful.

# CONTENTS.

# CHAPTER I.

## THE THREE STATES OF MATTER.

### LESSON 1.

SCIENCE is a word meaning literally knowledge, of whatever description it may be. The word is, however, now chiefly confined in meaning to the knowledge of natural things—those objects which we can see around us. These are, as you

know, of the most varied character, and not one of them but presents many points of great interest, and will well repay our careful study.

If we take a country walk, we see trees, and running brooks, fields with cattle browsing in them, the crows flying overhead, and many other interesting objects. All these we become acquainted with through the medium of our eyes, the most valuable of the senses with which we are endowed. Even if we have the misfortune to be blind, we are not entirely shut off from the outside world. It is true, we should have a very poor idea of a landscape unless at some former period we had possessed the power of vision ; but objects close at hand can be *felt* by our hands and other sensitive parts of the body ; and it is happily true that the touch of blind people becomes more delicate and accurate, thus in some measure compensating for the loss of the great gift of sight. Not only can we see and feel external objects, but we have other senses at work to render our knowledge of our surroundings more perfect. In taking our country walk, we *hear* the humming of bees as they pass from flower to flower gathering honey to add to their winter's store, the singing of birds in the trees, and the lowing of cattle in the distant meadow, or, maybe, the tinkling of the bell fastened round a sheep's neck ; and although we may see none of these, we are quite *certain of their* existence. Again, we *smell* the

perfume rising from the new-mown hay, or from clover, or from the wall-flowers in some cottage garden not yet in sight; and we can say without any hesitation that the objects from which these perfumes arise are somewhere at hand. And if we were told to "shut our eyes and open our mouth, and see what the king would send us," we should have no difficulty in saying that one fruit put in our mouth was a raspberry, and another a blackberry, although to the touch they appeared the same. The use of the word "see" in the above old saying is itself instructive. If our eyes are shut, we of course do not *see* what is inserted in the mouth, but taste it; here the two senses would tell the same truth, and so the name for one is substituted for the other.

There are thus five gateways through which knowledge can be received by us: sight, hearing, touch, taste, and smell; and of these, sight gives us by far the most information.

In this Science Reader we shall have to study many objects, including ourselves, and we shall require every one of our senses, and especially sight and touch, in order to obtain definite knowledge, besides which it will be necessary for you to try and retain in your minds, or, in other words, to remember, the information you will here receive.

All the objects we have mentioned, and, in fact, all the objects in the world, may be com-

gether under one common name of MATT

There are various forms in which mat

shall see there is one property which

common to all; it is this—every kind of m

pressure weighs and has a certain amount of

is supposed to contain. As there are diff

forms of matter there are different fo

light, electricity, heat, chemical affinity

mechanical force are the chief kinds, an

shall find that these are capa

being transformed into one another.

and force are the two subjects whic

occupy our attention for some time t

and we shall be able to learn many th

things concerning their relation to each

## LESSON 2.

Let us see how many different

matter there are. And in order to

judge at this point, try and name all

matter you can think of. Here is a l

it occurs to any co

stone, iron, clay, wood, water, salt, q

paraffin, olive oil, air, steam, coal-gas,

As regards the solid substances i

there is no difficulty in regarding

matter; and the liquids named—w

paraffin—are heavy, as they must

bodies, but seemingly

some bodies. They

rrounded by them, and yet A few chapters later on o prove that air has so much ll balance a column of water as in the case of the common eam, again, was produced from s of heat, and by cooling it gain. It has not been lost in ut has simply *changed its state.* a delicate pair of scales, and bottle full of steam, we should exactly as much as the water t was produced. Thus we find substances, or gases like air and , are possessed of weight, and e under the head of matter.

now classify the substances enu- re under three heads :—

| *Liquids.* | *Gases.* |
| --- | --- |
| Water | Air |
| Quicksilver | Steam |
| Oil | Coal-gas |
| Paraffin | |

ext place we will examine how these of substances differ from one another. k at any one of those under the first see that it possesses a definite and unless acted on by out- etain this shape. The sub- those named, appears least

to have a shape of its own is salt, but each particle of this, if examined with a magnifying glass, will be found to present a characteristic form, and it retains this unless acted on by moisture or some other agent.

Next look at one of the bodies in the second group—water, for instance. It has no definite shape, but takes the shape of the vessel in which it is contained, whatever that may be. Not only this, but the minute drops of which water consists have very little tendency to stick together, or *cohere*, as it is called. Pour water from the pitcher containing it on to the floor, and it flows away in various directions; salt so treated would remain in one heap.

Suppose we next turn on the tap of the gas chandelier, and pass the gas into a bottle without a cork. However we hold the bottle, whether with its mouth downwards or upwards, the gas declines to remain in it, and speedily diffuses itself throughout the whole room, mixing with the air, which is another gas.

Water and coal-gas agree in not having any definite shape, and in flowing in all directions unless prevented. Hence the name *fluid* (Latin, *fluo*, "I flow") is equally applicable to them and to all gases and liquids. But coal-gas differs from water in that it cannot be held in an open-mouthed vessel; and also in the fact that it can be compressed into a smaller space, whereas water is practically incom-

pressible. By means of these peculiarities all gases can be distinguished from liquids.

You will perceive that there is a gradation of properties between solids, liquids, and gases. Solids are those substances in which the particles have a strong tendency to cohere, liquids are those in which there is but little tendency to cohere, and gases are those in which there is a strong tendency for the particles to fly apart.

The degree of cohesion which binds even solids together varies greatly in amount ; and so we may have substances which, like salt, are in powder, or, like ginger-bread, are very brittle, or, like iron-wire, require considerable force to separate them.

## LESSON 3.

The state as regards solidity or fluidity of any given body is not necessarily a permanent thing. What is solid now may become a liquid, or even a gas ; or on the contrary, a gas or a liquid may be transformed into a solid. What is it that can work these wonderful transformations ? Well, what is it that will turn ice into water ? Putting it in a warm place, you will say. Quite so, and it is the heat which the ice there receives that effects the wonderful change from a solid to a liquid. In the same way water becomes steam, by means of the heat derived from the burning of coal in the fire, or by some like process.

Perhaps some of you have visited an iron foundry, and have seen iron in a molten, that is a melted condition; and even if you have not seen this, you will have seen in some neighbouring smithy how the iron, when white-hot, becomes soft and flexible. This is the first step towards melting it; a little more heat, and it would become a liquid. Probably iron has never been heated so much as to become a gas, but this is doubtless quite possible, if only sufficient heat be applied.

But what is it that will turn a gas into a liquid and a liquid into a solid? Take water again as an example. The vapour of this in the air is invisible, and there is constantly a large amount of it present. But if this moist air comes in contact with a cold wind, drops of water are formed, and descend as rain. The same thing is shown when we breathe out the moist air from our lungs on to a pane of glass. At once a film of condensed steam (that is, water) is formed on the pane. The cold glass has taken away so much heat from the steam that it becomes water.

Similarly all boys are glad when cold, frosty weather comes, for they know that the cold, if severe enough, will turn the water into ice, and bring skating within their reach.

In some cases the cooling of a gas will not *make it* a liquid; and so a division of gases *was made into* those that are *permanent* and

those that are not permanent, or *vapours.* Until lately there were a few gases that had never been made liquid; but a few years ago, even these so-called permanent gases were transformed into liquids by means of a strong pump, which forced a very large quantity of gas into a jar,—sufficient to fill it many times over.

A very important thing to remember is, that when any solid or liquid becomes a gas, it is not lost. It may have become invisible, but it exists none the less. We cannot alter the amount of matter in the universe by one grain; we can neither destroy an atom nor create it. MATTER IS INDESTRUCTIBLE. You might imagine that when a candle has burnt away, or a piece of paper has been thrown in the fire, it is done with; but this is far from being the case. A number of gases have been formed, of which carbonic acid is the most important, and has a wonderful after-history, as we shall learn later on.

**All our knowledge is obtained through the senses—touch, sight, hearing, smell, taste (and muscular sense).**

**Every kind of matter possesses weight.**

**There are three kinds of matter—*solid, liquid,* and gaseous. In solids**

**cohesion is great, in liquids little, and in gases absent.**

**The three states of matter are interchangeable, the changes being effected by means of heat.**

**No kind of matter can be destroyed.**

## CHAPTER II.

### THE PHYSICAL PROPERTIES OF LIQUIDS.

### LESSON 4.

THE power of maintaining its shape is perhaps the most characteristic property of a solid. In a liquid this property is nearly quite absent. But the fact that there are such things as *drops* of water, which are really composed of smaller particles, proves that cohesion is not entirely absent, though greatly diminished.

One most important character of liquids is, that they are practically *incompressible.* The amount of diminution in space occupied by a liquid when pressed greatly is so very small that it may be ignored. This property is important in connection with the next I have to mention ; for when pressure on a liquid is used for commercial purposes, if the liquid *could be squeezed* into a smaller space a certain

amount of force would be wasted in doing this before it could be utilised for other purposes.

Suppose we take a vessel like that in fig. 1, having several cylindrical openings of equal size fitted with movable pistons, and its interior filled with water or any other liquid. Suppose we press with a force equal to one pound at the piston, P, which is an inch wide; then the pressure at each of the other piston-guarded openings will be found to be equal to one pound, and a resistance equal to one pound must be applied to each to prevent the piston being forced out of them. This will happen at whatever part of the vessel the pistons are placed, and whatever may be its shape.

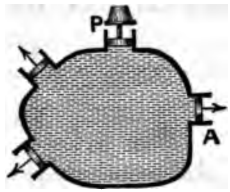

Fig. 1

Suppose that instead of having piston A the same size as piston P, it is double the size; then a resistance equal to two pounds must be applied to A in order to prevent the water rushing out of it when a pressure of one pound is applied to P. Similarly, if A were one hundred times as large as P, a pressure of one pound at P would require to be resisted by one hundred pounds at A. These remarkable facts may be expressed in a general statement, which is that *a liquid transmits pressure equally in all directions on the vessel in which it is contained.*

You will easily see in the last example that

one man pressing at the piston P will be able to use as much force, or, in other words, to do as much work, as a hundred men at the piston A, and more than ninety-nine men at A. A practical application of this is seen in Bramah's, or the *hydraulic press* (fig. 2), in

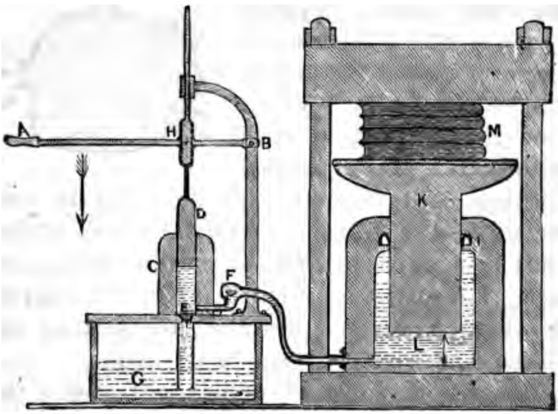


Fig. 2. THE BRAMAH PRESS.—D, the small piston, worked by the handle A B, G vessel containing supply of water to be pumped up into the small cylinder C, and forced, when the piston D descends, through the pipe F into the larger cylinder L. A valve at F prevents the return of the water. The large piston K is pushed up higher and higher as water is pumped into L, and thus compresses more and more strongly the books or other matter placed at M, between the piston K and the top of the press.

which there are two cylindrical vessels, communicating with each other by means of a narrow tube. Each cylinder is fitted with a water-tight piston, below which the water contained in the apparatus will stand at the same level in both cylinders. Now suppose *the smaller piston* (D in the figure) is sent down

with a force of one pound, and the larger piston K is ten times as large in area as D; then the latter will be sent up with a force of ten pounds; and if a soft body be held between the top of the piston and a fixed flat board, it can be greatly compressed. In this way bales of wool and other material are made to occupy a much smaller space. In the figure the pressure is being exerted on four books.

## LESSON 5.

If you fill a tumbler with salt, it can be piled up in any shape, but if you fill a tumbler with water, the upper surface at once becomes flat. How is this? The difference is due to the small amount of cohesion between the particles of water. They are freely movable, and so obeying the force of gravitation which pulls them towards the earth, they get into the lowest possible position in the tumbler, and all the particles of water having a similar tendency, the result is a flat surface.

Referring to the figure of the hydraulic press, you see that the water is at the same level in both cylinders when neither piston is pressed on. This is another example of the same principle—a principle which is often expressed thus: *water will find its own level.* The same thing may be shown by a fountain in the garden, or by connecting a long piece of narrow

tubing with the kitchen tap and carrying it up to a bedroom window. If the water-supply of the house is by means of a cistern, you will find that the water will rise in the tube exactly as high as the water in the cistern, and no higher.

For a similar reason, the reservoirs from which our drinking water is supplied must be higher in position than any of the houses to which water is supplied by underground pipes.

Liquids have weight, but in virtue of this weight, they do not press simply against the bottom of the vessel in which they are held. Instead of water, imagine a cylinder of ice were put into a vessel which it exactly filled. The weight of the ice is supported by the bottom of the vessel, and there is no pressure against the sides. You may take away the sides of the vessel, and the ice will remain in its position. But suppose the ice is melted. You can no longer take away the sides of the vessel without spilling its contents; the water presses on the sides as well as the base of the vessel.

At this point another important principle comes out, which we may illustrate thus. Take a glass cylinder open at both ends; make a flat disc of wood exactly fitting on to the end of the cylinder, and with a piece of string attached; plunge the cylinder, with disc attached, into a jar of water; the upward pressure of the water *against the disc will* keep it in position, and pre-

vent any water getting inside the cylinder (fig. 3). Now pour from above water into the cylinder very gently. When the water inside the cylinder reaches the level of that outside, the disc will become detached, for now it is pressed by the water equally in all directions, and so its weight makes it fall. This experiment proves that the upward pressure on the bottom of the cylinder is equal to the weight of a column of liquid extending from the bottom of the cylinder to the level of the water in the jar.

Fig. 3.

## LESSON 6.

Suppose we take a vessel of water, and imagine any part of it, such as M in fig. 4, to become solid without being altered in size or weight. Now the pressure on the sides of M must be equal in all directions, as it does not move from side to side, and the weight of M tends to make it fall. It follows, therefore, that there must be an upward pressure of water equal to the weight of M to prevent its falling.

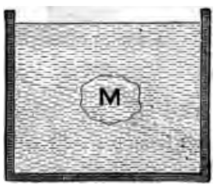


Fig. 4.

If any other solid body were immersed in water like M, it would similarly be pressed

upwards by a force equal to the weight of water displaced, and consequently would weigh so much less than it would in air. Thus if we take a pair of scales, and weigh in air a solid cube two inches in every direction, and then weigh it immersed in water, we shall find that the weight is considerably diminished;

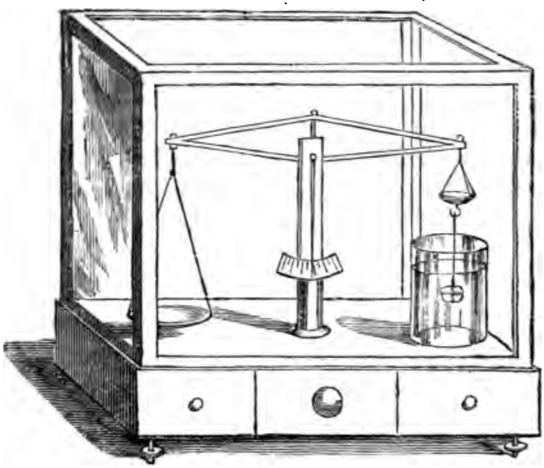

Fig. 5 Scales used in determining specific gravity.

and if we could weigh two cubic inches of water, we should find *its weight exactly the same as the diminution in weight of the solid cube.* This is only another illustration of the upward pressure or buoyancy possessed by liquids. An important application of this principle is the statement of the *specific gravity* of any substance; that is, its density as compared with

water, which is taken as a standard. Solids appear lighter when immersed in water, and the amount of diminution represents the weight of an equal bulk of water. The specific gravity is the figure which represents the original weight divided by the amount of diminution in water. An idea of the apparatus used for determining the specific gravity of a substance may be obtained from fig. 5.

## LESSON 7.

There are two other important properties of liquids, which we must mention before leaving this subject.

Probably you have often noticed how a small amount of tea at the bottom of a cup is rapidly sucked up by a lump of sugar. You can watch the liquid rising until every part of the lump is penetrated. The use of blotting-paper depends on a similar property. If you have the misfortune to make a blot, you put one corner of the bibulous blotting-paper into it, and it is speedily absorbed. Again, if you take a long towel and fasten one corner of it in a large jug of water, and allow the rest of the towel to hang loose, in a few hours the water of the jug (so far as the towel reached) will become transferred to the floor. Has it ever struck you to ask how the oil in a lamp rises up the wick to reach the place where burning is occurring? It gradually runs along and between the fine

fibres of the wick. In fact, in all these cases, the force of *capillary attraction* is working (Latin, *capillus*, a hair). This means that when tubes in which liquids are contained are very fine, the liquids *may* rise above their own level, contrary to the general law we stated previously. The reason for this difference is obscure, but the tubes or meshes into which a liquid rises must be very fine indeed; and even then not all liquids will rise above the general level. If we put a piece of blotting-paper or a lump of sugar in contact with some quicksilver, the latter will not rise, probably because it does not moisten the sides of the tubes.

Fig. 6. Experiment showing that colloids (*i.e.*, glue-like substances) have little or no tendency to pass through animal membranes, but that crystalloids have.

We shall find that capillary action is of importance in both plants and animals, as it greatly aids the free circulation of liquids in them.

Suppose we take an ordinary bladder (B, fig. 6), and having made a strong syrupy solution of sugar, half fill the bladder with it. Now place the bladder in a vessel containing water. After a time the bladder will be found to be full of a weaker syrup, owing to the entry of water, and the water outside will be found to have *become sweet.* Thus there has been a mutual

interchange between the syrup and water, and in accordance with the usual rule, much more liquid has passed from the water to the syrup than in the opposite direction.

The property which enables liquids thus to pass through membranes is called *osmosis*, or *diffusion*. There are some liquids which will not pass through animal membranes. If instead of putting syrup in the bladder, we put the glairy white of an egg, called albumen, in it, and then place the bladder in water, *no* albumen will find its way into the water, though some water will mix with the albumen. Similarly starch, glue, and many similar substances have little or no tendency to diffuse through membranes.

There are, therefore, two kinds of substances as regards their powers of diffusion—those which diffuse through animal membrane, and those which do not; the former are called *crystalloids*, and the latter *colloids* (*kolle*, Greek for glue). Crystalloid substances are those which, when dissolved, will diffuse through animal membranes, and when solid become crystallized; that is, assume definite shapes, like Epsom salts, alum, etc. Colloids are gum-like materials, which cannot be crystallized nor diffused through membranes. Osmosis has much to do with the life of plants and animals, as we shall find later on.

## Liquids are incompressible, and

they press equally in all directions. This gives rise to a great mechanical advantage, as in the hydraulic press. Water will find its own level.

Solids immersed are diminished in weight by an amount equal to that of the water displaced; thus specific gravities are estimated.

Capillary action occurs only in the case of solids with fine pores.

Colloids are indiffusible, crystalloids diffusible.

## CHAPTER III.

### THE PHYSICAL PROPERTIES OF GASES.

#### LESSON 8.

ONE of the chief characters of a liquid is, that when it is at rest its surface is flat. The particles of a liquid have not so much tendency to cohere as those of a solid, but they still remain in contact if undisturbed. Let us now compare these characters with those of a gas; and we will take air in this chapter as our example of a gas, though really it consists of a *mixture of two* gases, as we shall find later on.

Suppose we had a jar empty of air (obtained by means of the air-pump); on opening its stopper air would at once rush in and fill it. It would not be possible to let in air sufficient to half fill it, so that the lower half of the jar would contain air, and the upper half be a *vacuum* (that is, empty of everything). The particles of which air consists would simply expand, and occupy the whole space. We may state this in another way, by saying that cohesion is entirely abolished in a gas, and that instead there is repulsion between its various particles.

Gases, even though they may be invisible, possess weight, and different gases possess different degrees of weight.

In a later chapter you will learn how to prepare carbonic acid gas. Suppose you have a stoppered bottle full of it, also a delicate pair of scales, on one side of which you have carefully balanced an empty jar with an open mouth (fig. 7). Of course this jar is not really empty, but is full of air, for air gets into everything that is not "air-tight." Now hold the mouth of the bottle containing carbonic acid over the bottle containing air, just as if you were going to pour water from it. Very soon the arm of the balance on which the lower bottle rests will descend, although you have not touched it with the bottle out of which you poured the carbonic acid. The reason of this is, that carbonic acid

is a heavy gas, and falling into the bottle on the scales, drives out the air from it; and the difference between the weight of the same volume of carbonic acid and of air is quite sufficient to send down the arm of the scales.

That some gases are heavier than others may be proved by another experiment. Prepare hydrogen gas by the method described in a

Fig. 7. Experiment illustrating the heaviness of carbonic acid gas.

later chapter (Lesson 35). Take one of the pink india-rubber balloons you often see for sale in the streets. If you fill this with air and throw it up, it will soon fall again, the air not being light enough to keep it suspended. But if you fill it with hydrogen gas, it will soon mount to the top of the room, and you may have difficulty in getting it down again.

Here, then, are three gases, of which hydrogen is lighter and carbonic acid heavier than air.

A very important property of gases is, that they have a strong tendency, when put together, to mix freely. In the experiment in which we poured carbonic acid into a jar containing air, it is true that the former drove out the latter for the time being; but if we left the carbonic acid for a few hours, we should find that the greater part of it had disappeared, *diffused* into the surrounding atmosphere. This is a most important matter; if it were not for it, the impure gases which constantly collect in houses (from ourselves, from the burning of candles and gas, and from other sources) would, after a time, kill us all. But happily, fresh air from out of doors finds its way in, and it ought to be helped in by all possible means; while the bad air finds its way out, and so life becomes possible.

## LESSON 9.

The *atmosphere*, which is the main gas we are concerned with in our daily life, possesses weight like all other gases. We are unaware of its existence under ordinary circumstances, but when we move rapidly, and so push against the air, or when there is a wind,—that is, a rapid current of the air pushing against us,—we become aware of its existence.

That the air exerts considerable pressure may be proved by the sucker which boys are

fond of playing with. This is a circular piece of soft leather, with some strong twine fastened to its middle. On moistening the leather and pushing it against a flat stone, its margins adhere to the stone, but the centre is dragged away when the twine is pulled. Thus a vacuum (S in figure) is produced between the leather and the stone, and the air outside, pressing on the leather, keeps it closely in contact with the stone.

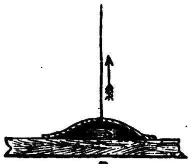

Fig. 8. Section of leather sucker, showing the vacuum (S) caused when the string is pulled.

The total atmospheric pressure which the human body has to support amounts to several tons, being nearly fifteen pounds to every square inch, and the only reason why we do not feel this enormous pressure is, that it is equally exerted in every direction.

Now air being possessed of weight, you will easily understand that the part nearest the earth is of a greater density than that above, being pressed on by all the air lying over it, while, on the other hand, the air becomes rarer—that is, of less density—as we ascend. It is generally stated that its limit is about forty-five miles above the level of the sea, though there is considerable doubt on this point ; if it were all the same density throughout, it would not reach more than five miles above the sea.

You know that in the ordinary water-pump, *when the piston* is raised by means of the

handle, the water follows it, and so is raised from a considerable depth. For a long time the reason of this was unknown. It was said that "nature abhorred a vacuum," and so the water rose to fill it; but this is simply a statement and not a reason. But finally Torricelli, a pupil of Galileo, after thinking the matter over carefully, came to the conclusion that the water ascended to fill the vacuum because the air in the well pressed it up, and that, in fact, the air would force it up until the pressure of the column of water was equal to the atmospheric pressure. He did not remain content with this theoretical proposition,—as those who lived before him had been content with saying that "nature abhors a vacuum,"—but set about to prove it. In order to do this, he took a glass tube about thirty-three inches high (C D, fig. 9), filled it with quicksilver, and then inverted it over a bowl containing

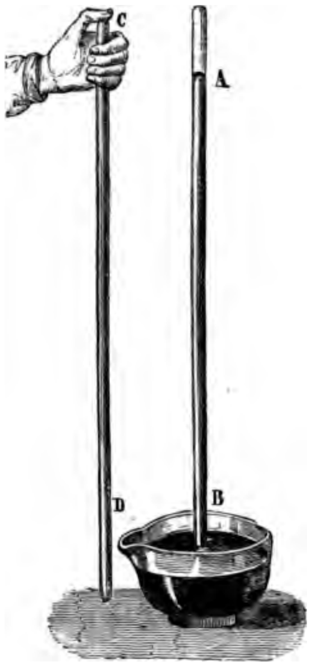

Fig. 9. How to fill barometer tube.

quicksilver. The quicksilver stood in the tube (at A) a little more than thirty inches above the mercury in the basin, the space above being a vacuum. He concluded that the pressure of the atmosphere keeping the quicksilver at this height in the tube was equal to the weight of thirty inches of quicksilver. This inverted tube is called a BAROMETER, and is used for testing the atmospheric pressure at any given place. It is found to vary at times, and so indications as to the weather to be expected may be obtained.

Fig. 10. A BAROMETER.

Pascal, who was born about fifteen years after Torricelli, completed the proof of the fact that the atmospheric pressure is the cause of the quicksilver remaining suspended in a tube. He argued that if the suspension of the quicksilver in the barometer is due to the atmospheric pressure, then as the atmospheric pressure is less at the top of a mountain, the quicksilver ought to be lower in the barometer. He accordingly ascended a lofty mountain with his barometer to put this point to the test, and found, as he had expected, that the quicksilver fell nearly three inches. The fall in the quicksilver corresponded to a certain weight of air left below, and as this weight is proportionate to the height, we may roughly estimate the height of any place by the height of the quicksilver in the barometer.

## LESSON 10.

We have described the barometer as an instrument for estimating the atmospheric pressure. There are several other instruments owing their action to the atmospheric pressure which we may now consider.

You all know the common BELLOWS, and have doubtless used them in "blowing the fire." There is a round hole on the under-surface into which a wooden valve fits (A, fig. 11), only opening inwards. When the upper half of the bellows is lifted up, a partial vacuum is formed in the interior; air rushes in through the valve to fill it: now the upper part of the bellows is lowered again, the valve is at once closed, and so the air is driven out along the nozzle.

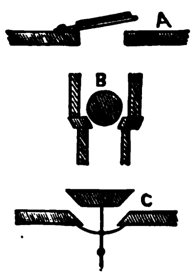

Fig. 11. Three kinds of valves: A, hinged valve; B, ball valve; C, plug valve.

A similar valve is used in the construction of the air-pump and the water-pump.

The AIR-PUMP is used to deprive a vessel, as far as possible, of the air it contains. Its essential parts are shown in fig. 12.

A is a glass vessel fitting accurately on a flat smooth plate. In the middle of this plate is an opening, which communicates by means of a bent tube with a cylinder, B, and where the tube joins the cylinder there is a valve, *a*, only opening upwards. A piston very accurately fitted works

in the cylinder, B, and this possesses a valve, *b*, only opening upwards.

Now suppose that A is full of air, and the piston at the bottom of the cylinder. If the piston be raised, a vacuum is produced in B, and the air in A forces up the valve, *a*, to fill this. The consequence is that the air which previously only filled A now fills A and B. When the piston is forced down again, the first effect is to shut the valve, *a*, but as the piston

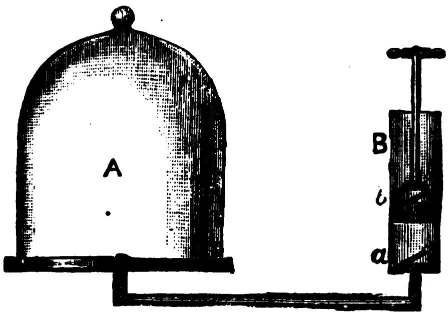

Fig. 12. THE AIR-PUMP.

descends, the air in the cylinder is forced through the valve, *b*, and escapes. In this way a certain amount of air has been got rid of. If the piston be again pulled up, the remaining air in A expands to fill A and B, and at the next down-stroke of the piston, that part of it which has reached B is forced out through the valve of the piston.

Thus the air in A is rendered rarer and rarer, *but it is impossible* to get rid of all of it by this

process, though we may for all practical purposes *exhaust* it. The vacuum produced by the inverted tube full of quicksilver, on the other hand, is a perfect one. It is generally known as the *Torricellian Vacuum*.

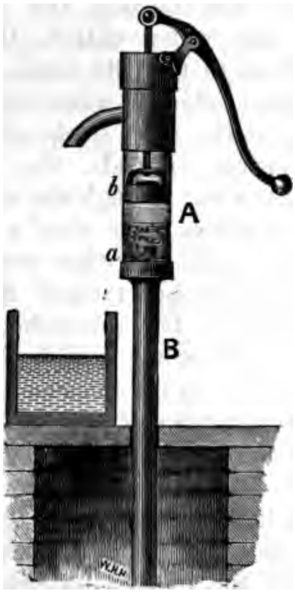


Fig 13 THE WATER-PUMP.

The WATER-PUMP resembles in principle the air-pump, differing, however, in having attached to the cylinder A (fig. 13) a long tube, B, which reaches down to a reservoir of water. At the point where the tube joins the cylinder there is a valve (*a*) opening upwards, and in the

piston which accurately fits into the cylinder is another valve (*b*) opening upwards. The effect of raising the piston is to produce a vacuum in the cylinder. Some air rushes up through the valve from the tube to occupy this vacuum; consequently the atmospheric pressure on the water outside the tube is now greater than that on its inside. In order to restore the balance, water rises in the tube. When at the next stroke of the pump handle the piston descends, the air in the cylinder is driven out through the upper valve; and when the piston again rises a vacuum is once more produced, and what remains of air in the tube below rushes through the valve to occupy its space. The atmospheric pressure outside forces the water still further up the tube, and probably at the third or fourth stroke water reaches the cylinder, and finding its way through the valve of the piston, is forced out at the spout.

There is a limit beyond which water cannot be pumped up by an ordinary pump—namely, thirty feet. If the tube below the cylinder is longer than this, the water will not rise into the cylinder. The meaning of this is, that the atmospheric pressure is equal to the weight of a column of thirty feet of water, just as it was equal to the weight of thirty inches of quicksilver. In fact, we might make a barometer of water, only it would be so very clumsy.

## LESSON 11.

The SYPHON is a bent tube open at both ends, having one leg longer than the other. It is used to convey liquids from one vessel to another at a lower level. Perhaps you have seen a man selling lemon-water in the street. He has a large glass jar containing the liquid. Into this a bent tube is inserted, with its longer arm hanging below, the lower end of which is capable of being opened or stopped by a

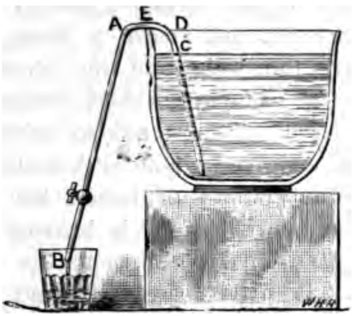


Fig. 14. THE SYPHON.

tap. The way in which the man gets the liquid to flow from the glass jar up the short tube and down the long tube is this. He first of all fills the whole of the tube with water, holding the two ends with two fingers. Then he puts the short arm of the tube into the liquid, and unless he secures the end of the longer arm, the liquid will at once begin to run from it, and will continue to do so until all his lemonade is exhausted. This

method of transferring liquids from one vessel to another is very convenient in some instances, especially where vessels are too large to lift, or have no taps attached.

How is the transfer of liquid effected? It is the atmospheric pressure that is at work again. To begin with, it is necessary that the tube should be full of liquid. Imagine a small portion of water at E (fig. 14), the highest part of the tube. The atmospheric pressure on the liquid in the higher vessel tends to drive this onwards to the left with a force which is lessened by the weight of the short column of water, C D. The atmospheric pressure acting from the lower vessel, tends to drive it to the right with a force which is lessened by the weight of the column of water, A B. But the column A B, being longer, is heavier than the column C D. The consequence is that the water at E is driven forwards and down to the lower vessel, and the same process goes on until the lower end of the short arm is no longer in the liquid. You will understand that in this case, just as in the common pump, the apparatus will not act if the column of liquid in the shorter arm, C D, is heavier than the atmospheric pressure. Thus, in the case of water, it must be less than thirty feet, and for quicksilver less than thirty inches.

## *In gases* **cohesion is absent.**

Gases tend to diffuse in every direction.

The atmospheric pressure will support thirty inches of quicksilver, and thirty feet of water.

The atmospheric pressure varies with the height above the sea, and at the same height varies at different times.

The air-pump is used to exhaust a space of its air.

The vacuum produced is never perfect, unlike the Torricellian Vacuum.

The water-pump will raise water to the top of a tube thirty feet long.

The syphon is used to convey liquids from one vessel to another, by a bent tube with two unequal arms.

# CHAPTER IV.

## SIMPLE MACHINES.

### LESSON 12.

A MACHINE is an instrument for doing work. Originally man did all his work with his own muscles, and these are able to do work of great complexity. But after a time he found that there were many things he could not do well, or, at any rate, could do better with the help of some appliance; then he turned inventor. At first his machines were rude and clumsy, but gradually they acquired better adaptation to their purposes, until all the wonderful machines we now possess were brought into use. For instance, although we might be able to break pieces of wood with our hands, yet with a hatchet or saw we could do it much better in every way. Again, we could carry a heavy sack of corn on our backs, but by putting it in a wheelbarrow the task becomes much easier. All machines agree in two points. There is the *power* which does the work required, and there is the resistance to be *overcome, the* work to be done, called the

*weight.* The resistance may be of various kinds: when we raise a weight from the ground, it is the earth's attraction that has to be overcome; when we cleave a piece of wood, it is the cohesion between the particles of the wood; when we draw a heavy body along a rough road, it is the friction between the body and the road.

*Friction* is an agent or resistance which is constantly a hindering factor in all machines, the power used having not only to do the work it is specially intended for, but also to overcome the friction of the machinery. The more perfect a machine is, the less the friction between its individual parts; and thus a great economy of force is effected. Putting oil into the joints and wheels of machinery, carefully polishing their surfaces, and other measures, are all means for lessening friction. In some cases friction is purposely brought into action. Thus in going downhill in a carriage the brake is turned on. This means simply that one of the wheels is made to rub hard against a flat surface, and so the force and rapidity with which the carriage descends is diminished. Friction, again, is brought into action when a train is stopped by the brake. Perhaps you have seen sparks flying from the wheels just before the train stops. These are due to the friction of the wheels against the lines producing so

much heat as to cause a spark. It is an instance also of the transformation of mechanical force into heat and light. Friction produces heat, and the heat is so great as to cause sparks of light.

By the use of a machine for any particular purpose, we do not absolutely gain anything. *What is gained in power is always lost in space.* Thus, taking the instance of the hydraulic press described in our 4th Lesson, if the area of one piston is an inch and the other a hundred inches, then if a pressure of ten pounds is applied to the smaller, it will raise a hundred times that amount—that is, a thousand pounds put on the larger piston. But as the amount of water in the press does not alter, the larger piston being a hundred times as wide as the smaller, will only rise one hundredth part of the space that the smaller one descends. In other words, more power is thus exerted, but the resulting movement is correspondingly less.

The simple machines are the lever, the wheel and axle, pulleys, the inclined plane, the wedge, and the screw. We will examine each of these in turn.

## LESSON 13.

A LEVER is a rigid rod which turns on a fixed point. The fixed point is called the *fulcrum*, and the parts of the rod on either side of the fulcrum are called the *arms*. In the game of

see-saw we have a very common example of a lever. A plank is laid across some solid support, such as a large stone, and at each end a boy gets astride the plank. Imagine one boy up in the air and the other resting on the plank at the level of the ground. The weight of the first boy now alters the balance, and sends the second boy up in the air. In this case the fixed support is the fulcrum, the first boy forms the power, and the second boy the weight to be lifted. If the two boys are


Fig. 15. LEVER OF THE FIRST KIND.

of equal weight, the fulcrum is fixed at the middle of the plank. If one boy is lighter than the other, the part of the plank between him and the fulcrum (that is, his arm of the lever) is made longer than the other portion. Thus *a longer arm of the lever compensates for a diminished weight.* But although the smaller boy, in virtue of his having the longer piece of plank, can make his partner rise into the air, with perhaps only half the weight, yet he cannot *make him* rise so high as he himself rises

when his turn comes. What he gains in power he loses in space.

There are three kinds of levers, according to the relation of the fulcrum to the arms of the lever.

The crowbar is a good example of the first kind, as you will see from the figure (fig. 15). The weight is at one end, the power (force of

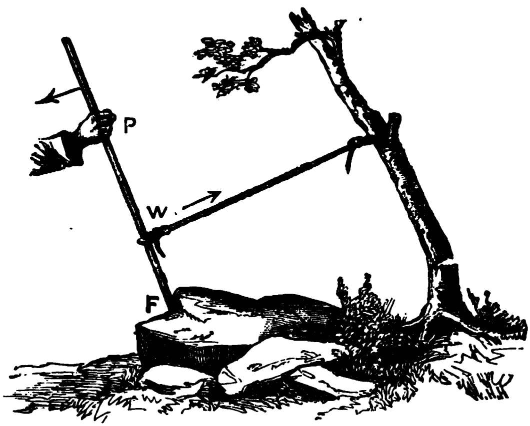


Fig. 16. Lever of the Second Kind.

the hand) is at the other end, and the fulcrum (F in figure) between these points.

In fig. 16 you see an example of the second kind of lever. A rope is attached to an old tree at one end, and to the middle of an iron rod at the other. The rod is firmly fixed against a rock at one end, and this is the fulcrum, while the muscular force of a man exerts the power at the other end of the rod. Here the

weight acts at the attachment of the rope to the rod (at W), that is, between the fulcrum and power. In a wheelbarrow we have a lever of the second kind. The power is exerted at the handles of the barrow, the weight is in the barrow, and the fulcrum acts at the axle of the wheel. A rowing-boat is another example of the same kind. Here the fulcrum is at the point where the oar enters the water, the power is exerted at the other

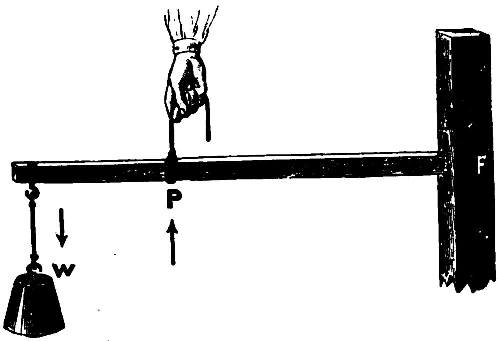


Fig. 17. LEVER OF THE THIRD KIND

end of the oar, and the weight of the boat acts at the rowlocks where the boat presses against the oar.

An example of the third kind of lever is seen in fig. 17, where a rod of wood supporting a weight at one end is fixed into a wooden upright (the fulcrum) at the other end, and is supported between these points from above.

The treadle of a turning-lathe is also an *example of this* kind of lever. It will be

evident that the power not acting at the end of the lever in this kind, is at a disadvantage; but this disadvantage is in many cases more than counterbalanced by the readiness of action ensured. For this reason it is especially common in the mechanism of the movements of the body.

## LESSON 14.

The WHEEL AND AXLE may be regarded as a modification of the lever. It consists of two cylinders continuous with one another, the central part, called the *axis*, being common to both. One cylinder much larger than the other is called the *wheel;* the smaller one is the *axle.* If the wheel is made to rotate either by means of a handle, or by spokes as in fig. 18, the axle likewise rotates, and a rope attached to the axis will be wound round it, and so any weight at the end of it raised. One of the commonest examples is the windlass.

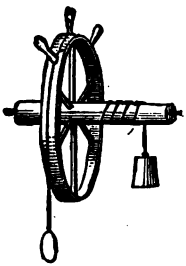

Fig. 18.
WHEEL AND AXLE.

A PULLEY consists of a circular plate, the circumference of which is grooved to receive a cord. The pulley is made to revolve freely round an axis fixed into a framework called the block. Where there is only a single pulley *fixed to* a framework, all that it can do is to *alter the direction* of a force (fig. 19). But

this is often a most important matter. Pulling is generally easier than pushing, and, as a rule, greater force can be exerted. Where we have movable pulleys a distinct mechanical advantage is gained, though the rule still holds good that what is gained in power is lost in space. Take the example of a man who is sitting on a board

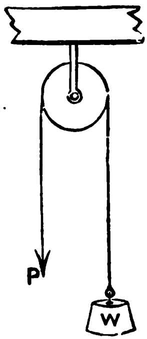


Fig. 19.
SIMPLE PULLEY.

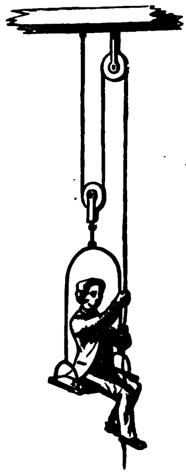

Fig. 20.

attached to a movable pulley. By pulling at the other end of the rope he will be able to support himself by a force equal to one-third of his own weight (fig. 20).

By means of an INCLINED PLANE a body can be raised to acertain height by the application of a power less than the weight of the body. You have *often seen* barrels rolled into a cart along

a steep plank with comparative ease, when if they had been lifted into the cart, it would have been a very different task.

The WEDGE may be regarded as a double inclined plane. Unlike the latter, it is movable instead of fixed, and is used for separating and splitting substances. The thinner the wedge the farther it will be able to penetrate; and hence its mechanical advantage is increased in this way. Knives, choppers, and chisels are all examples of the wedge. In the case of the wedge it is not usual to push it simply against the substance to be separated, but to use a series of blows. In this way the amount of force is greatly increased; and it is found generally that when the resistance to be overcome is very great, a series of sudden shocks are more effectual than continuous efforts.

Fig. 21. THE WEDGE.

The SCREW consists of a cylinder with a uniform projecting thread arranged in a spiral manner round its surface. This may be forced, as in the case of a screw nail, into resisting objects by a screw-driver, or may be inserted into a concave cylinder called the *nut, which* has a spiral cavity on its inner

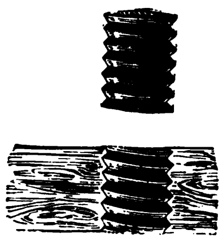

*Fig 22.* THE SCREW.

surface corresponding to the projections on the screw.

**A machine is an instrument exerting force different in direction and intensity from that applied.**

**Friction prevents the perfect action of machinery.**

**In all machines, what is gained in force is lost in space; or what is gained in space is lost in force.**

**A lever consists of two arms and a fulcrum. There are three kinds of levers. according to the relative position of these parts.**

**The other simple machines are the wheel and axle, pulley, inclined plane, wedge, and screw.**

# CHAPTER V.

## HEAT.

### LESSON 15.

IN the last chapter we have had much to say about *power*. The kind of power considered has been mechanical, but this is not the only kind in existence. There are several other forces or powers of even greater importance than mechanical, namely, heat, light, electricity, and chemical affinity ; and these we must also consider.

These different forces at first sight seem to have little or nothing in common, but as a matter of fact they are closely allied ; indeed, so closely that they can become transformed into one another. Modern science has come at last to the grand generalisation that they are only *different forms of motion*, and that they can be transformed into one another. Thus if you rub a brass button for a few minutes, it becomes so hot that you can scarcely hold it. Mechanical energy has developed heat.

We shall find later on that electricity can be *produced by* rubbing a piece of glass with a

silk handkerchief, and that by means of the electricity sparks of light can be obtained. Similarly, any of the different forces named can be transformed into any other. But although this transformation may occur, the actual amount of force or energy present in the universe is just the same as it has always been. It may alter its form, but no force can be annihilated or created. This is the principle of the *conservation of energy.*

The different forces of the universe are utilised by man to do his work. A given amount of heat will do a definite amount of mechanical work if properly used. It is true, we cannot change all the heat into mechanical force without any waste. We can entirely convert mechanical energy into heat, but a certain proportion of heat in the converse process is always wasted. Take the example of the *steam-engine,* which is by far the most important machine for turning heat into motive power. In this machine, by means of heat, water is changed into steam. The steam thus produced is introduced from the boiler (fig. 23) into the cylinder below the piston, which is consequently raised to the top of the cylinder. Let the supply of steam from the boiler be now cut off by shutting the valve A, and the steam in the cylinder be allowed to escape into the open air by opening the valve B. Next let the steam from the boiler be introduced along the upper

pipe through the valve C; the piston will consequently descend to the bottom of the cylinder. When it has got there, C is closed again, and the steam above the piston is discharged into the air by opening the valve D, so that when steam is introduced below the piston, it will at once mount again. In this way an upward and

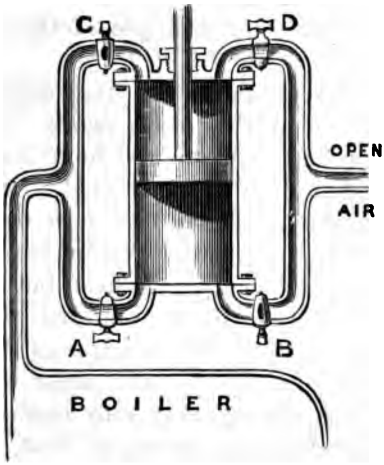


Fig. 23. Diagram to illustrate the principle of the Steam-engine.

downward movement of the piston is produced, and this movement will effect a large amount of work, such as pulling a train, or working the machinery of a factory, if the piston is connected with appropriate apparatus for directing the force.

However carefully the steam-engine is worked, *a large proportion* of the heat produced by

burning the coals is wasted ; it is found that not one-fourth of the energy of the heat is converted into mechanical force, the rest being lost (that is, dissipated as heat) in the process of working.

## LESSON 16.

The amount of sensible heat in any body is called its *temperature*. The thermometer is used for measuring the temperature. It is founded on the principle that all bodies expand when heated. The quicksilver in the glass tube of the thermometer expanding a certain amount for every increase of a degree in temperature, and therefore rising in the tube, will measure the amount of heat.

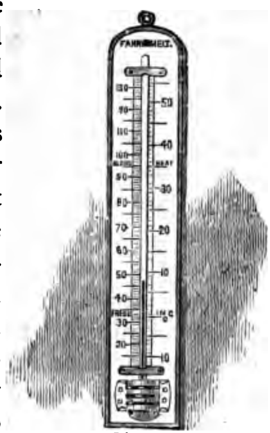
Fig. 24.

The rule that heat increases the size of every body applies equally to solids, liquids, and gases. They all swell or expand under the influence of heat. Inasmuch as heat causes substances to expand, the withdrawal of heat that is cold will cause them to contract. There is only one important exception to this, namely, water. This follows the rule in contracting until its *temperature is* lowered to 4° Centigrade ; but

from this point until it reaches 0° (the temperature at which it becomes ice) it expands. The consequence is that ice is of less density than water between 0° and 4°, and will therefore float on its surface. Imagine how lamentable would be the result if water followed the usual rule, and diminished in size until it became ice! The ice being heavier than water, would sink to the bottom, the water would rise to the surface and become ice in its turn, and so on until whole rivers and seas would become a solid mass of ice. But the thin layer of ice which covers lakes and many rivers in winter, as we actually find it, forms a casing which keeps the water comparatively warm, and so the lives of fishes are preserved. This exception is a wonderful one, and all the more so when we consider its exact adaptation to its end.

The expansion of gases by heat is perhaps the most difficult to realize. An easy experiment, however, will at once prove this expansion. Half fill a bladder with air and hold it in front of the fire. The heat soon makes the air expand and swell out the bladder to its full capacity.

Expansion is not the only effect produced by heat. There may be also a *change of state*. Take a lump of ice, for instance. This, when heated, speedily becomes water, and if the heat is raised sufficiently, it becomes steam. The temperature at which water begins to boil is

known as the *boiling point.* Bubbles appear on the surface, which are really gaseous water escaping into the air. The boiling point in any given case varies with the nature of the liquid. Ether will boil if simply warmed ; water requires to be raised to 100° Centigrade. It also varies with the pressure to which the liquid is subjected. The lower the pressure, and the lower the temperature at which a liquid will boil. Thus, although water usually boils at 100° C., at the top of Mont Blanc it boils at 85° ; and this temperature is not high enough to boil an egg. Special pans have to be made for cooking, in which the steam produced is confined so as to increase the pressure, and therefore the boiling point. The following experiment will prove that the boiling point varies with the pressure. Half fill a flask, like that in fig. 25, with water, and boil it in the open air. The steam arising from the water will drive all the air out of the flask, the steam taking its place. Now cork the flask tightly and invert it, and when it has ceased boiling place a piece of ice on it, as in the figure; or pour some cold

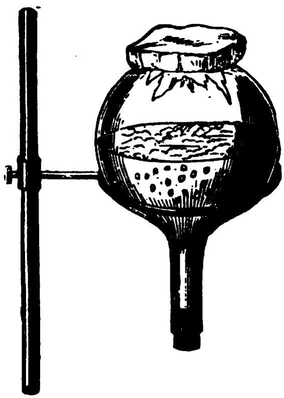

Fig. 25.

water over it. The water at once recommences to boil, owing to the cold water having condensed the steam, and so withdrawn the pressure from the water and allowed it to boil at a lower temperature—in fact, without any heating at all.

## LESSON 17.

You will remember that we defined the temperature of any body as its *sensible* heat. From this you will infer there is heat which is insensible or imperceptible. This is the fact, and such heat is known as *latent heat*, which means literally *hidden* heat.

In order to convert a given quantity of boiling water into steam, a much larger amount of heat is required than is necessary to maintain the water at the boiling point (that is, 100°). And yet the steam only possesses the temperature of 100° C. It is evident, therefore, that a certain amount of heat is used in changing water into steam, which does not affect the thermometer.

In changing ice into water, a certain amount of heat is similarly required, which does not affect the thermometer. This may easily be proved. If we take an ounce of water at 0°, and another ounce at 79°, and mix them, the temperature of the mixture will of course be the mean—that is, 39·5°; but if we take an ounce of ice at 0°, and mix it with an ounce of water at 79°, the ice will be melted, but the *resulting two ounces* of water will not be at

39·5°, but at 0°. In other words, the whole of the heat of the water has been used up, or rendered latent, in changing the ice into water.

We may define latent heat, then, as that heat which is used in changing solids into liquids, or liquids into gases, and which does not affect the thermometer.

If you think for a moment, remembering the principle of the conservation of energy (see page 51), you will infer, from what we have said, that when a gas becomes a liquid, or a liquid becomes a solid, a certain amount of heat is evolved, it escapes from its latent condition; and this is found to be the case.

It is necessary that we should consider in the next place how heat is carried from one body to another, or to different parts of the same body.

There are three chief ways in which heat is conveyed. The first of these is by *radiation*. Any substance which is hotter than its surroundings sends waves of heat in every direction. This is how we get heat (as well as light) from the sun; the sun is hotter than our world, and so waves of heat travel through the millions of miles intervening until they reach us, and supply us with that warmth without which our lives would be impossible.

*Conduction* is another plan by which heat is distributed. If you put one end of a poker in the fire, the heat travels along it from particle to particle until the other end becomes too hot

to hold. But if you were to put a long glass rod in the fire, the other end would not become hot, however long it were held there. We thus arrive at the conclusion that some substances conduct heat well—that is, are *good conductors*—while others conduct it very little, or are *bad conductors*, and may even be *non-conductors.* Wool and feathers are bad conductors of heat, and this is the reason why these substances have been provided as the clothing of animals; they serve to prevent the heat of their bodies escaping to the surrounding world.

## LESSON 18.

Liquids and gases convey heat very little by conduction, but in them another method comes into force, namely, that of *convection.* Take a glass jar nearly full of water into which a few fragments of cochineal have been put to colour it, and heat this from below by a spirit lamp. Very soon you will be able to see ascending currents of heated water rising up the centre of the jar, while the colder water descends along the sides of the jar. In this way water is repeatedly being heated at the bottom of the jar, and, becoming lighter when heated, ascends; while colder and heavier water descends, and becoming in its turn heated, once more ascends to the surface. This process goes on until all the water has reached the uniform temperature of 100°, when, if the heat is still further applied,

it is rapidly converted into steam. In the freezing of water we have an example of convection on a large scale. The water on the surface, say of a lake, is cooled down to 4° C.; it is therefore heavier than the water under it, and consequently descends. The warmer water thus brought to the surface is cooled down to 4° in its turn, and so on until all the water of the lake is at 4°. Now comes the wonderful exception we have already alluded to. The water on the surface being cooled down below 4°, will not descend, because it is lighter than water at 4°; the consequence is that only a comparatively thin layer of water can be converted into ice.

*Winds* are another remarkable example of convection. A wind always means that the air at one place is warmer than at another. The sun shines vertically, and therefore with great force on the parts of the earth at and near the equator; the consequence is that heated and therefore lighter air rises into the upper parts of the atmosphere. The place of this ascending air is taken by colder air, which rushes in from the poles of the earth on both sides. In this way we have an under-current (forming the *trade-winds*) sweeping from the poles to the equator, and an upper current of heated air (called the *anti-trades*) travelling from the equator to the poles.

It is probable that land and sea breezes may

be explained in a similar way. During day the land gets much more heated than the sea; hence there is an upper current of heated air from land to sea, and a lower current of cooler air from sea to land, the latter forming the *sea-breeze.* But after sunset the earth cools more rapidly than the sea, and then we have an under-current from land to sea, constituting a *land-breeze.*

**Heat is a form of motion, and can be transformed into other forms of motion. The steam-engine is a machine for converting heat into mechanical force.**

**All bodies expand by heat. The chief exception is water between 0° and 4° C.**

**The boiling point of any liquid varies with the pressure.**

**In changing solids into liquids or liquids into gases, a certain amount of heat becomes latent.**

**Heat is distributed by radiation, conduction, and convection.**

**Convection especially occurs in liquids and gases.**

***Winds* are caused by convection.**

# CHAPTER VI.

## LIGHT.

### LESSON 19.

WHEN any substance is heated, it gives off rays or waves which travel with enormous rapidity (by the process called radiation), until they reach surrounding substances. These waves, if the substance is not very hot, are invisible. When we place a large covered can of boiling water in a room, we see nothing coming from it, and yet it will raise the temperature of the whole room. But if the temperature of the substance heated be very high, the rays become visible as light, still travelling with the same velocity as before. Thus when we heat a poker in the fire, even before it becomes red-hot, it gives off rays of heat if removed from the fire; but when it becomes red-hot, and still more when it becomes white-hot, it also gives off rays of light, and if it could be kept at that temperature, might be used as a means of lighting a room.

The exact rapidity with which light travels has been estimated in a very interesting way. To explain this I must tell you a little about

the stars. A large star called Jupiter has a number of smaller stars called satellites revolving round it, just in the same way as the moon revolves round the earth. One of these (S, fig. 26) travels the whole circuit in 42 hours 28 minutes 36 seconds. Now our moon disappears out of our sight at a known time each day, owing to its being on the other side of the earth; similarly the first of Jupiter's satellites disappears at intervals of 42 hours 28

Fig. 26.

minutes 36 seconds, being hidden from us on the other side of Jupiter.

But at the same time that the satellites are revolving round Jupiter, the earth itself is revolving round the sun. It thus happens that sometimes we see the first satellite disappearing behind Jupiter from the point *a*, and at another time, owing to the revolution of the earth, from the point *b*, which is further away from the satellite by the width of the earth's orbit (*fig.* 26). In the latter case it was found that *the rays of light* took 16 minutes 36 seconds

longer to travel from the satellite to the eyes of the person observing on the earth. This increase of time of course corresponds to the time the rays of light took in travelling from *a* to *b*; and the distance between *a* and *b*—that is, the width of the earth's orbit—being known, the rate of travel per second was easily calculated, and found to be 186,000 miles per second.

This is the velocity with which light travels through space, and it may give you some idea of the enormous distance separating us from the

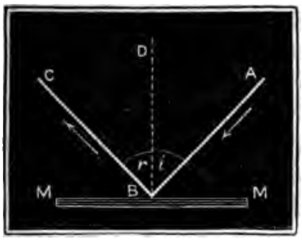


Fig. 27.

sun when we state that a ray of light takes more than eight minutes to travel from the sun to the earth, having 94,000,000 miles to go.

Probably you have often played with a small hand mirror, and catching the beams of sunlight, have sent them in some other direction, perhaps into a companion's eye. You are able to do this because the rays of light are *reflected* from the mirror; and it is found that if the rays of light fall vertically on the mirror, they will return in the same direction; while if they

fall obliquely on it, they will be reflected with a corresponding obliquity in another direction. Thus suppose a ray of light, A B, as in fig. 20, falls on the mirror M M; it will be reflected in the direction B C, the angle *i*, which A B makes with the vertical line B D, equalling the angle *r* made by B C with it.

This explains how we see ourselves in a mirror. Of course there is no substance really in the mirror; but the rays of light from our faces reaching the mirror, are reflected into our own eyes, and so we see our faces as though they were in or behind the mirror.

When an image is formed in a flat mirror, it is of the same size as the object of which it is the reflection. But it is of a different size when the object is viewed in a curved mirror, and it may be upside down or erect according to the curve of the mirror. A very simple example will make this plain. If you take an electro-plated tablespoon, and look at yourself reflected in its rounded convex surface, the image is smaller than your own face, and is erect—that is, the right side up. You must make some allowance for the difference of curve of the spoon in the two directions. If you look at the image with the spoon vertical, your face appears "as long as a fiddle"; while if you view it with the spoon horizontal, it appears wider than *it really is*. If you next look at your face in *the hollowed* concave surface of the spoon, hold-

ing it some distance away, it is upside down or inverted. Thus with convex mirrors we get erect images, with concave mirrors we get inverted images, unless the object is held very near.

## LESSON 20.

Perhaps you have noticed that when a long stick is held obliquely with about half of its length in a stream of water, the half in water appears bent up so as to be crooked. The reason for this apparent bending will be better understood by an experiment. Put a coin at the bottom of a basin, and then place yourself so that the side of the basin *just* hides the coin from your view. If you

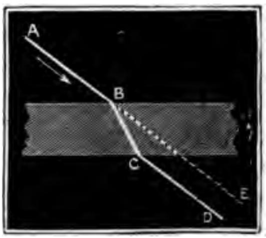

Fig. 28.

now get some one to fill the vessel with water, without disturbing the coin, it will come into view. When we see an object, it means that rays of light must come from it to our eyes; but in this case the rays of light from the coin before the water was added did not reach your eyes. It follows, therefore, that the water must have altered their direction—in fact, bent them—so that the coin can be seen, as it were, round a corner. This bending, which always occurs when light passes from one medium (like air)

to another (like glass or water) of a different density to it, is called the *refraction of light.* It would occur, for instance, when a ray of light passes through a thick flat piece of glass like that in fig. 28. The ray A B, instead of continuing in the same direction on to E, is bent or refracted on entering the glass into the direction B C; but on emerging from the undersurface of the glass, etc., it resumes a direction parallel to its original one, because now it is passing from a denser to a rarer medium.

If instead of passing through a flat piece of glass, a ray of light passes a wedge-shaped piece (like those hanging from the ornaments called lustres), it is bent even more than in the former case. Its whole direction is altered, and it emerges in a direction more inclined towards the base (that is, the thickest part) of the wedge (fig. 29). Such a wedge-shaped piece of glass is called a *prism.* The original direction of the ray of light falling on the prism is continued in the dotted line, and this will show you how great the deviation is.

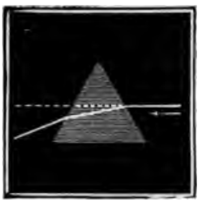

Fig. 29.

Let us vary the shape of the glass still further, and take a circular piece of glass which is thickest at the centre and thins off at the edges, as seen in section in fig. 30. This arrangement is usually called a convex *lens.*

If rays of light enter it, they will all be bent, as in the prism, towards the thickest part of the lens, which is at the centre, and will come to a single point on the opposite side, F, called the *focus*. If a piece of paper be held behind a lens in the sunlight at the point where the sun's rays come to a focus, the paper may even be set on fire.

When a convex lens is held close to any object, we see a considerably magnified image

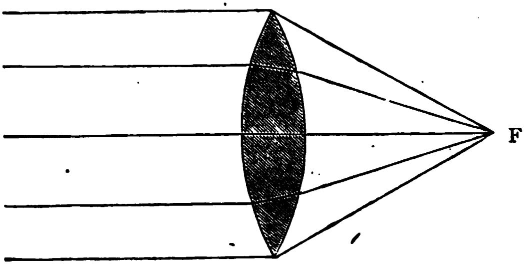


Fig. 30.

of the object. This is the most common use to which convex lenses are put. They are most commonly known as *magnifying glasses*. A *microscope* is simply an arrangement of convex lenses in a long tube, so combined as to magnify the image very greatly.

In the human *eye* (fig. 31) there is a double convex lens (*k*) composed of a dense transparent material. In front of this is a curtain (*i*) varying in colour in different individuals, and enclosing an orifice called the pupil, which admits

light to the lens. The curtain can be altered in size, so as to allow more or less light to enter the eye. By means of the lens of the eye, all rays of light are brought to a focus on a delicate membrane (*c*) called the retina, which is situated at the back of the eyeball, and carries the impressions of light along the optic nerve

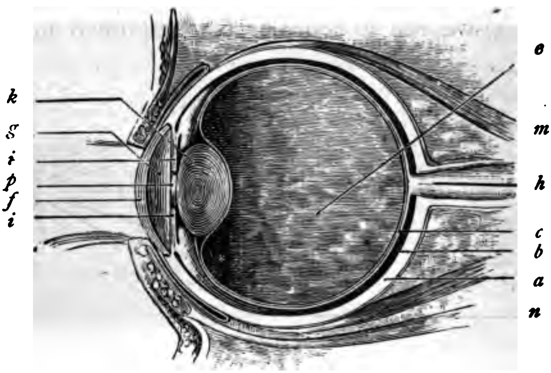


Fig. 31. Section of the human eye, showing, *a*, sclerotic coat; *b*, choroid membrane or uvea; *c*, retina; *e*, vitreous humour; *f*, cornea; *g*, aqueous humour; *h* optic nerve; *i*, iris; *k*, crystalline lens; *m* and *n*, muscles to move the eye; *p*, pupil.

(*h*) to the brain, where they are really perceived. Unlike all other lenses, the lens of the eye can have its shape altered very rapidly, to suit itself for rays of light coming from a distance or from near at hand. In this way all rays are certain to be brought to a focus at the right point on the retina.

## LESSON 21.

Probably you have noticed in a diamond ring that if a ray of sunlight falls on it, it shows all the colours of the rainbow. Or in the lustres, which I have already mentioned, you will have noticed a similar beautiful play of colours. A drop of dew may show the same; and so does the rainbow itself. With regard to the latter, may we not infer from the dewdrop that

Fig. 32. Breaking up ray of white sunlight into its coloured constituents: *r*, red; *o*, orange; *y*, yellow; *g*, green; *b*, blue; *i*, indigo; and *v*, violet.

the colours of the rainbow are in some way due to the falling of light on the multitudes of drops of water in the clouds, among which the rainbow appears?

It remained for Sir Isaac Newton to discover the reason of the phenomena I have named. We have already seen that light, in passing through a prism, is directed away from its original course. Newton took such a prism, and placing himself in a dark room, he cut a

narrow vertical slit through the shutters, so as to admit sunlight. In the path of the sunlight he placed a prism, as in fig. 32. The light was consequently turned up towards the base of the prism. But instead of being a luminous slit as before, it was now a broad band of many colours, beginning with red at the lower end, and passing gradually through orange, yellow, green, blue, and indigo, to violet at the other end. He also found that he could no longer see the ray of light at K, the point where it was visible in its course from the slit before the

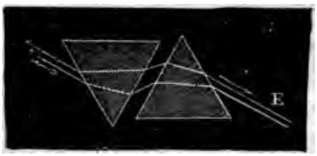


Fig. 33. Recombination of the constituent colours of white light.

prism was interposed, but had now to place his eye at a higher level. Thus the prism had bent the rays of light, but more important still, it had proved that *each ray of sunlight was composed of a number of rays of different colours.* On no other supposition can we account for the appearance of the different colours on the opposite side of the prism. The rays of different colours are bent in a varying degree by the prism, and hence become *dispersed* in passing through it. To complete the proof that white *light is really* composed of a number of different-*coloured lights,* we must not only split up the

former into the latter, but recombine the different colours into white light. This can be done in the same way as Newton did his original experiment; only after the ray of light is split up into its constituent colours by the prism, another prism is placed beyond it turned the opposite way, as in fig. 33. The effect of this second prism is to reunite the different-coloured rays into the original white light. Thus our proof of the composite character of white light is completed.

**Light travels nearly 190,000 miles per second.**

**When a ray of light falls obliquely on a flat surface it is reflected at an angle equal to the incident angle.**

**Rays of light in passing from one medium to another are refracted; that is, bent out of their course.**

**Prisms and lenses effect this refraction of light, and always towards their thickest part.**

**The microscope produces magnified images by means of convex lenses.**

**A prism splits up a narrow ray of light into its component colours; these may be recombined into white light.**

# CHAPTER VII.

## ELECTRICITY AND MAGNETISM.

### LESSON 22.

As long ago as six centuries B.C., amber (of which the Greek name is *electron*) was known when rubbed with silk to have the property of attracting light substances, and from the Greek name of this substance is derived the name of the modern science of electricity.

Since that time it has been found that many other substances—such as sealing-wax and glass—when rubbed possess a similar attractive power.

This attractive power exhibited by many substances after friction may be illustrated by a few simple experiments. Take a large stick of sealing-wax and rub it briskly with a piece of flannel, making sure that both the sealing-wax and the flannel are thoroughly dry. Now hold it near a small pith ball, suspended by means of a silk thread from a glass support, as in fig. 34. The pith ball is at once attracted to the sealing-wax, and comes in contact with it; but as soon as this happens it flies away as quickly as it approached. In fact, the previous attractive force is now converted into a repulsive force.

Next take a glass rod, and having rubbed it briskly with a silk handkerchief, bring it near *the pith ball* which has been repelled by the

ng-wax. It is at once attracted towards glass rod.

/e see, then, that a pith ball touched with ›ed sealing-wax will be afterwards repelled ubbed sealing-wax, but will be attracted by bbed glass rod.

.et us try and explain these facts. The hanical energy exerted in the friction of ng-wax or glass develops a certain amount

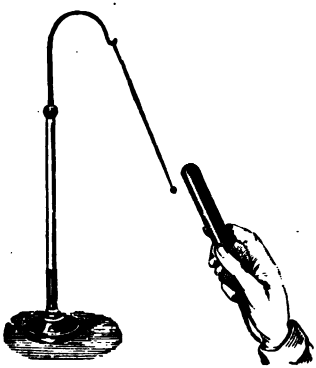

Fig. 34.

force called electricity, but the electricity loped by rubbing sealing-wax differs from developed by rubbing glass, inasmuch as pith ball repelled by the former is attracted the latter. A different name is given to e two kinds of electricity, that produced he friction of glass being called *positive*, and produced by the friction of sealing-wax *tive.*

Another fact is evident from the experiments made. The rubbed sealing-wax attracted the pith ball until the latter touched it; then the attraction was changed into repulsion, the reason being that a portion of the electricity of the sealing-wax passed into the pith ball. Thus two bodies charged with the same kind of electricity repel each other. But when the rubbed glass rod was brought near the pith ball charged with negative electricity, the latter was attracted. We thus arrive at the rule that bodies charged with unlike forms of electricity attract each other, while those charged with like forms repel each other.

It is not necessary here to speculate as to the nature of electricity, but it is very necessary to remember that there are two kinds. It is also important to note that electricity cannot be developed without effort—*out of nothing, nothing comes.* Considerable friction, which means mechanical work, has to be exerted before the electricity appears. Later on we shall find that in batteries electricity is developed by chemical decomposition; but here, again, a certain amount of energy is involved. Similarly when one kind of electricity combines with another, as it can be made to do, a spark is commonly produced, and a certain amount of heat likewise, exactly equivalent to the previous amount of electricity.

Now if we rub a brass rod for a very long

time, no electricity will apparently be developed. But if we hold the brass rod by means of a glass handle, and then rub it, very soon electricity is produced, just as it was in the sealing-wax or glass. The reason why it did not appear to be present in the first case was that as rapidly as it was formed it passed away from the brass into one's hand, owing to the fact that brass is a good conductor of electricity, just as it—like all other metals—is a good conductor of heat. We may divide bodies, therefore, so far as electricity is concerned, into *conductors* and *non-conductors*, the two classes gradually merging into one another. Some substances, which under ordinary circumstances are non-conductors, like glass and sealing-wax, may become conductors when moist air is present. Moist air conducts electricity very well; hence it is very important to perform electrical experiments on dry days, and to warm the apparatus in front of the fire.

## LESSON 23.

We have hitherto spoken chiefly of the movements of bodies when brought under the influence of electricity. But we must try and find out now what is their actual electrical condition when so acted on.

Suppose we take an apparatus like that in fig. 35. C is a sphere which has been charged *with positive electricity*, and is placed on a glass

support (thus *insulating* it ; that is, preventing the electricity from escaping). A B is a metal cylinder placed near C, but not electrified. From it are suspended a few pairs of pith balls, and it is insulated like C. When A B is placed near C the pith balls diverge from each other, the divergence diminishing until a point near the centre of the cylinder is reached, where they are vertical, as at the commencement of the

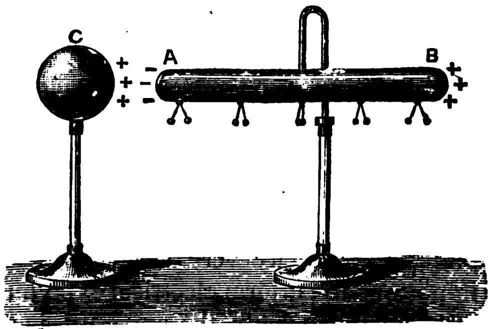


Fig. 35.

experiment. Beyond this point the pith balls diverge again more and more until the opposite end is reached.

It can easily be shown that the pith balls near A are charged with negative, while those near B are charged with positive electricity ; for an electrified stick of sealing-wax repels the balls at A, and attracts those at B. The divergence of the pith balls in the experiment is due, as you will probably have already concluded, to

the fact that being charged with the same kind of electricity, and having touched, they are at once driven away from one another.

The pith balls derived their electricity from the brass cylinder. One-half of this is charged with negative, the other with positive electricity. The only way we can explain this development of electricity in the cylinder is by assuming that the cylinder (like all other bodies) contains two kinds of electricity, negative and positive, which under ordinary circumstances are in combination, and so neutralize each other ; but when an electrified body like the ball C is brought near it, its attraction suffices to separate the neutral electricity into its two parts,—the negative electricity is attracted to the end of the cylinder nearest the positively charged ball, while the positive electricity is repelled to the other end of the cylinder. This method of separating electricity by the presence of an electrified body near is called *electrical induction.*

If we bring the cylinder still nearer the ball until they nearly touch, a spark will be seen to pass between them, resulting from the combination of the positive electricity of the ball with the negative electricity of the cylinder ; and the latter will now be left charged with positive electricity.

If before trying the last experiment we attach a pointed brass rod to the end of the cylinder, it will be *impossible* to obtain a spark. The

point carries away the electricity very rapidly, not leaving enough for the production of a spark.

Franklin was the first to prove that lightning and electricity are the same thing, the only difference being that an electric spark is only a few inches long at the most, while a flash of lightning may reach several miles.

A very important application of the fact that points carry electricity rapidly away has been made in the shape of *lightning conductors.* These are pointed metallic rods placed above lofty buildings, and carried down into the earth; thus the building is protected from the shock of the tremendous electrical sparks produced by lightning.

## LESSON 24.

In all the preceding experiments electricity is developed by friction, or by induction from a body in which electricity has already been produced by friction.

But the electricity which is most commonly used is that developed by placing plates of two different metals—such as copper and zinc—in a weak solution of sulphuric acid (fig. 36). Such an apparatus is called a *battery.* A wire is connected with each of the plates, and it is found that a current of positive electricity escapes from the copper end of the apparatus (B.2), while a current of negative electricity escapes from the zinc end (1.A).

It is usual to have several cups containing these plates of copper and zinc connected by wires, as in the figure, and thus the strength of the current is greatly increased.

It is important to know what is the force developing the current in this experiment. We have learnt to expect nothing from nothing; what, then, produces the electricity in this case? After a time we shall find that the zinc plates are getting worn away. The sulphuric acid has

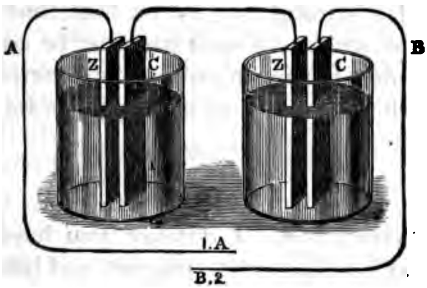


Fig. 36. A GALVANIC BATTERY.

acted chemically on them, producing a salt called the sulphate of zinc; and this chemical action is the origin of the force producing the electric current.

The production of the sulphate of zinc prevents, to a large extent, the continued action of the sulphuric acid on the zinc; and this is why this particular form of battery after a time loses its strength.

Other forms of battery, such as Grove's and Daniell's, are so arranged that the products of

the chemical action are decomposed, and so prevented from weakening the action.

Whatever be the length of the wires at the ends (or *poles*) of the battery, the current will, if sufficiently strong, pass through them, and may be made, as in the case of the *submarine telegraph*, to carry an electric current thousands of miles in a very few seconds.

There is a certain kind of iron ore which possesses the property of attracting iron. This is called a natural *magnet* or loadstone. We shall soon see how a steel bar may be endowed with similar, but much stronger magnetism.

The chief property of a magnet is its power

Fig. 37.

of attracting iron. I daresay you have often played with a horse-shoe magnet, and have been able to pull a needle about on a piece of paper by moving a magnet under the paper, or to make a needle stuck in a cork float from one end of a pail of water to the other.

If we take a bar magnet like that in fig. 37, and scatter over it some fine iron filings, they will be attracted towards its two ends, and arrange themselves somewhat as in the figure. We may infer, therefore, that there are two centres of force in a magnet, situated near each end, and called the *poles* of the magnet.

*If the* magnet be itself suspended horizontally

by a thread it will point in a particular direction, and however much it may be disturbed, will always return to this position when at rest. In this country the direction the magnet takes is very nearly north and south (about $20^{\circ}$ to the west of the north). This is explained by regarding the earth as a gigantic magnet, and just as unlike electricities attract each other, so unlike magnetisms do. The *marked* pole of the magnet (which points to the north) is attracted by the *unmarked* pole of the earth, which is at the north, while the unmarked pole of the magnet is attracted by the marked south pole of the earth.

It is this property of turning always north and south which makes the magnet of such great value to mariners. A magnet is always placed in a case on deck in such a position that the man at the helm may be able to "see the points of the compass," and so know in what direction to steer.

## LESSON 25.

Soft iron may be made magnetic by contact with a magnet, but it soon loses its power. Hard steel is the best material for making a magnet. It is managed in this way. A steel bar is taken, and two powerful magnets. The marked pole of one of these is placed at the centre of the steel bar, and the unmarked pole of the other close to it. Then these two are

drawn to opposite ends of the bar, and this process is repeated several times. The steel bar will now be found to be a magnet.

It is interesting to note in this connection the effect of an electric current on a magnet. A magnet is suspended as shown in fig. 38. The earth tends to keep this in a north and south position parallel to the wires above and below the magnet. These wires are separated from each other by a glass vertical portion, and thus are kept insulated. First pass a current

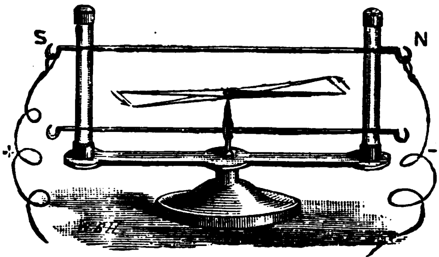


Fig. 38.

through the upper wire by connecting the wire with the poles of the battery. If the current be a strong one, the needle will turn almost at right angles to its former position. On withdrawing the current, the needle returns to its former position. If a current, be next passed through the lower wire in the same direction as before, the needle is again turned considerably out of its position, only in the opposite direction to its previous one.

The power of turning or deflecting a magnet

essed by an electric current is used as a ns of signalling in the electric telegraph. his a current is passed along a wire from distance. When it arrives at its destination ırns a magnet, and this may be made to

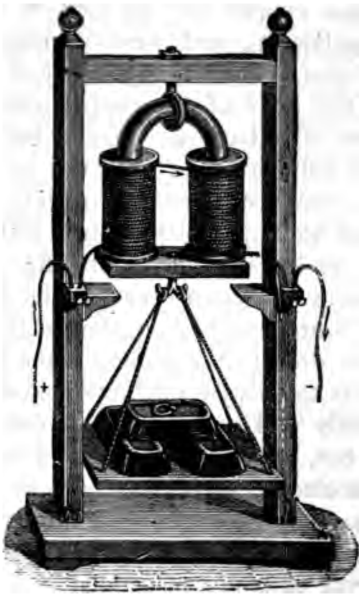


Fig. 39. Magnet produced by Current.

e a bell, and so indicate that a message :ing sent. The strength of the current is :ased by not making it return along a second of wires to the office whence it started, *letting it* pass into the earth after it has

delivered its signals. In this way, also, the expense of the telegraph is diminished, as only half the quantity of wire is required.

We have described the action of an electric current on a magnet. Let us see what would be its action on an unmagnetised piece of iron. Take some copper wire encased in thread (so as to insulate it), and wind it round a thick piece of iron shaped like a horse-shoe. Now connect the ends of the copper wire with the two poles of a battery. If the battery is in action, it will be found that the iron has acquired the power of attracting other iron towards it, and will hold up a plate of iron with a weight attached to it, as in the figure (fig. 31). But the moment the connection of the horse-shoe with the battery is broken, the weight and the iron plate drop to the ground,—the horse-shoe has lost its temporary magnetic power.

Not only will an electric current act on a magnet, but, on the other hand, a magnet will act on an electric current. Suppose we have a coil of carefully insulated wire through which a current is passing; this of course will turn a magnetic needle carefully suspended in a particular direction. If we quickly introduce a strong magnet within the coil, a secondary current is, for the moment, produced, which will turn the suspended needle in an opposite direction. By repeatedly introducing and withdrawing the magnet at frequent intervals, a series of cur-

rents is produced, equivalent to the amount of mechanical energy expended.

These currents may be used for various purposes. One of the most important purposes to which they have been applied is for producing the *electric light*, which can now be seen to some extent in most towns.

Not only can electricity be used in generating light, but in producing chemical changes. An electric current passed through water will decompose it into the two gases of which it consists, as we shall find in a later chapter.

**There are two kinds of frictional electricity—positive and negative.**

**Unlike kinds of electricity attract, like kinds repel each other.**

**Metals are good conductors of electricity, so is moist air.**

**Electricity may be induced by bringing an electrified body near a neutral one. Lightning is an immense electric spark.**

**The galvanic current is produced when two metals are put in an acid liquid.**

**A magnet points nearly north and south; it forms the mariner's com-**

**pass. Steel is the best material for making a magnet.**

**An electric current parallel to a magnet deflects it.**

**An electric current passed round a piece of iron makes it a magnet.**

**A magnet passed into a coil of wire through which a current is passing develops a current in the opposite direction.**

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## CHAPTER VIII.

### ELEMENTS AND COMPOUNDS—METALS AND NON-METALS.

### LESSON 26.

WE have already learnt that the world in which we live is made up of matter in three forms or conditions—solid, liquid, and gaseous. Everything around us can be placed in one of these three great divisions. But if you examine, say, a number of solid substances, you must be struck with the fact that though they all agree in being solid, yet in other particulars they widely differ. Thus take a piece of chalk, of *clay*, of sand, and of charcoal. Here are four *solid substances*, but how very dissimilar they

are! It is evident, therefore, that the arrangement of matter under the divisions of solids, liquids, and gases does not tell us everything about them by a long way. We must find out some more accurate classification. Let us see if the following illustrations will help us.

I daresay you have all seen lime-kilns, in which limestone is heated by means of a great fire. The result of this heating is that the limestone becomes quicklime, and at the same time there is driven off from the limestone a poisonous gas called carbonic acid, of which you have already learnt something, and will learn more hereafter. Many poor tramps have been attracted by the good fires of these lime-kilns, and having gone to sleep in front of them, have never woke again, the carbonic acid gas having suffocated them. The action of heat on the limestone evidently shows that it is composed of, *at least*, two kinds of matter; viz., a gas (carbonic acid) and a solid (quicklime). We may represent this in the form of an equation thus:—

Limestone = Quicklime + Carbonic Acid Gas.

There is a red powder commonly known as red precipitate, but more correctly as red oxide of mercury. This can easily be obtained at a chemist's shop. Keep it in a safe place, as it is poisonous if swallowed. Take as much of this substance as can be piled on a shilling;

place it in a test tube; heat the tube over a spirit-lamp (fig. 40). The red powder soon alters its colour, and after a time you will find that part of the inside of the tube is coated with a shining layer, like that on the back of a looking-glass, and, in fact, identical with it. Put a match which has been lighted and blown out, but still remains red-hot, into the mouth of the tube

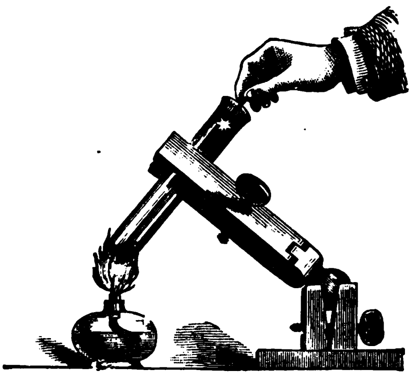

Fig. 40.

while you are heating the latter. At once the match relights, and burns with a very bright flame. This power of relighting a dying light shows that a new gas has come off from the red powder; and this gas we shall learn later is called oxygen.

Now take the tube and scrape the silvered part with a thin stick. Soon the silvering *will disappear*, and instead you will see two or

three little globules of quicksilver (also called mercury). It is evident that red precipitate powder can be broken up into liquid quicksilver, and a gas called oxygen ; or putting it in the form of an equation,—

Red Oxide of Mercury = Mercury + Oxygen.

These examples will serve to show you that in many cases what is apparently *simple* matter is really composed of two or more simpler parts. The process by which a compound substance is split up into its component parts is called *analysis* ; that is, loosening or separating, that being the meaning of the Greek word analysis.

Suppose I take the quicklime obtained by heating limestone in the previous experiment, and pour on it some water. At once the quicklime becomes very hot, and crumbles down into a soft mass. The quicklime was caustic—that is, it would burn many other substances ; the slaked lime, produced by the union of quicklime and water, is not caustic. The process by which we thus put together two or more substances, and build up another substance having different properties from those of the substances we started with, is called *synthesis*, from two Greek words, *sūn*, together, and *thesis*, a placing, signifying a putting together or combination.

## LESSON 27.

These two processes of synthesis and analysis are constantly being employed in chemistry, as you will see from the experiments which we shall describe. In every case you ought, if possible, to perform the experiments here described, as you will thus obtain a much better understanding of the subject than by simply reading about them.

We have seen that limestone and red precipitate powder can each be split up into less complex substances. And we might have given many other examples of the same thing. But not all the substances around us can thus be split up. You may treat sulphur or charcoal or silver as you like, and you will be able to obtain nothing from them but sulphur or charcoal or silver. You will see, then, that this fact that some substances can be split up, and others, cannot furnishes us with the classification of matter from a chemical standpoint, for which we were searching. We will make two great classes of matter—1st, that which cannot be split up, and is called *elementary matter*, and 2nd, that which can be split up, and is called *compound matter*.

The substances coming under the first head are called *elements*; those coming under the second head are called *compounds*.

Any substance, whether it be solid, liquid, or gaseous, is either an element or a compound.

Here is a list of some common substances classified according to this method :—

| *Elements.* | *Compounds.* |
| --- | --- |
| Charcoal | Common Salt |
| Silver | Limestone |
| Lead | Epsom Salts |
| Copper | Sugar |
| Quicksilver | Glass |
| Sulphur | Water |
| Oxygen Gas | Carbonic Acid |
| | Ammonia |

The compounds all contain at least two different elements, very often more. You might imagine that as there are so many different substances around us, there would be a very large number of elements ; but as a fact, the world is entirely made up of sixty-four elements, which are variously mixed and combined so as to form a large number of different compounds.

And of these sixty-four elements there are nine or ten which form the greater bulk of the earth, two elements, oxygen and silicon, together forming about seventy per cent. of the solid earth. Oxygen is the most abundantly diffused element, constituting a large part of the air, water, and the solid earth.

Five of the sixty-four elements are gases at the ordinary temperatures, two are liquid, and the remaining fifty-seven solid. But you have learnt in previous lessons that a solid substance may be made liquid or gaseous by the application of heat, and a gas or liquid may be made

solid by the withdrawal of heat; and this is true of any of the sixty-four elements.

## LESSON 28.

The elements are usually subdivided into two classes—viz., *metals* and *non-metals.* There are forty-eight metals, and as there are sixty-four elements altogether, it follows there must be sixteen non-metals.

All the metals are solid except quicksilver (mercury), which is liquid at ordinary temperatures. We may take a bar of iron as an example of a metal. You will notice that this can be polished, so as to produce a surface that will answer the purpose of a looking-glass. Charcoal or sulphur, on the other hand, could not be thus polished. Again, if you hold a bar of iron with one end in the fire, very soon the other end will become too hot for you to maintain your hold. Of this you have a familiar example when a poker is put in the fire. But if you hold one end of a long stick of charcoal in a flame, the charcoal will burn at that end, but you will have no difficulty in maintaining your hold of the other end. This difference is expressed by saying that metals are better conductors of heat than non-metals. Of course the metals are not all exactly alike in other particulars, though they all agree in having a bright surface when polished, and in being good conductors of heat. Metals differ much

in colour as well as in other respects ; copper is red, silver is white, gold yellow, iron grey, and so on. One or two elements, like arsenic, in some particulars resemble metals, but in others resemble non-metals, and it is doubtful under which head we ought to put them. Here is a list of some of the commoner elements, classified into metals and non-metals :—

| *Metals.* | *Non-Metals.* |
|---|---|
| Mercury | Oxygen |
| Silver | Hydrogen |
| Gold | Nitrogen |
| Iron | Carbon |
| Lead | Chlorine |
| Zinc | Sulphur |
| Nickel | Silicon |
| Sodium | Phosphorus |
| Potassium | |

Two or more elements combine together to form compounds. But we may have two or more elements mechanically mixed together, and yet not forming a compound. What then constitutes the difference between a *mechanical mixture* and a *chemical compound?* Perhaps we can best explain it by examples.

Put a piece of chalk and two or three lumps of sugar into a mortar, and pound them well together with a pestle, so well that it would be impossible to pick out the chalk or the sugar. Have we now obtained a compound substance by the union of chalk and sugar? We shall see. Pour some water on the contents of the mortar, and stir it up well. The sugar soon

dissolves, and for a time the chalk forms with the water a creamy-looking liquid ; but if you allow it to stand for a time, the chalk settles to the bottom, while the sugar is left dissolved. It is evident, therefore, that the sugar and chalk were simply mechanically mixed by the pestle, and not closely united, or, in other words, not chemically combined.

Next take some fine copper filings and powdered sulphur. Mix these as thoroughly as possible in the mortar. Now wash the mixture with water. The sulphur, being much lighter than copper, will be washed away if the water is poured into the mortar in a good stream ; or the sulphur may be dissolved by a liquid called bisulphide of carbon ; while the copper is left behind in the mortar in both cases.

Next take some more copper filings and sulphur, and heat them together in a large test tube over a spirit-lamp. The mixture soon becomes black, and quite unlike either sulphur or copper. And if you try to wash out the sulphur by means of water, or to dissolve it by bisulphide of carbon, you will be unable to do so. The copper and sulphur have combined together to form a substance which is different from either of the two elements from which it was formed. This new substance is, therefore, *a chemical* compound, and not a mere mixture *of sulphur* and copper.

Now when two substances join together to form a chemical compound, the union always occurs with the development of a certain amount of heat. When quicklime and water are brought together great heat is evolved, and a new compound is produced. Similarly when strong oil of vitriol or sulphuric acid, as it is also called, has a small quantity of water added to it, great heat is produced. But when substances are only mechanically mixed, there is no development of heat. We may say, then, that a chemical compound differs from a mechanical mixture in having very different properties from those of the elements of which it is composed, and in giving rise in its formation to heat.

**The world is made up of elements and compounds.**

**There are sixty-four elements.**

**Elements are metals or non-metals, there being forty-eight metals and sixteen non-metals.**

**A mechanical mixture differs from a chemical compound in not having its properties greatly changed.**

# CHAPTER IX.

## THE CHEMISTRY OF AIR.

### LESSON 29.

IT will be impossible for us to study the subject of chemistry in detail, but we will take the more important elements and compounds, and study these a little more closely than you did in Standard IV., paying special attention to those which enter into the composition of plants and animals.

It is quite impossible to understand the build and functions of plants and animals without some knowledge of chemistry.

Let us begin by studying the *Chemistry of the Air.* We have already discussed its physical properties; now we will try and discover what it is composed of.

Take a bell-jar (fig. 41) which has a glass stopper capable of being removed, and a large dish containing water; next get a flat piece of cork, cut a hollow in its centre, and place on it a piece of phosphorus about the size of a pea. Now light the phosphorus by means of a match, and put the bell-jar quickly over the burning phosphorus. The bell-jar, of course, was full of air, though apparently empty. Dense white fumes are formed by the burning of the phosphorus, due to the union of the

phosphorus with part of the air. At the same time you will notice that the water is rising from the dish into the bell-jar, until it fills one-fifth part of the latter. The white fumes soon disappear; they are dissolved in the water.

Now *what* is the explanation of this? What were the white fumes? Why does the water ascend one-fifth of the way up the bell-jar and no farther? The white fumes were due to the union of the phosphorus with oxygen in the

Fig. 41.

air of the bell-jar. The oxygen being taken away, the water rises up to take the place of the partial vacuum thus produced. And the fact that the water rises only one-fifth of the height of the jar shows that only one-fifth of air is formed of oxygen.

Suppose we now examine the air that is left behind in the jar. Remove the stopper, and plunge a burning taper into it. At once the taper goes out. It is evident, therefore, that the air left after the taking away of oxygen is

very different from what it was before. The name given to the gas remaining after the burning of phosphorus in air is *nitrogen*—a name meaning "nitre generator," and which was given to it because it is an important constituent of nitre or saltpetre. The name given to the gas which combined with phosphorus is oxygen, which means "acid generator." Taste the water that has risen in the bell-jar after all the dense fumes have disappeared. It is very sour, not unlike vinegar, or a very sour apple. If you take some specially prepared blue paper, called litmus paper, and put this in the sour liquid, it is at once turned red. Now oxygen forms compounds with elements like sulphur and phosphorus, which, when dissolved in water, are sour, and turn blue litmus paper red. It is therefore called an acid generator, or oxygen.

We have learnt thus far that air is composed of four parts of nitrogen to one part of oxygen, that nitrogen is a gas putting out tapers and other lights, and that oxygen is an acid producer when combined with elements like phosphorus.

## LESSON 30.

To learn more about oxygen it will be necessary to take some substance from which we can obtain it pure. We have such a substance in chlorate of potassium. Put some

of this white solid into a Florence flask, the cork of which has a hole bored through, into which a bent tube is inserted (fig. 42). The other end of the bent tube is placed under the open mouth of a jar full of water, which has been inverted in a pneumatic trough. This trough can be imitated by having a large basin, with a raised platform of wood, through the middle of which a hole has been bored for the tube as in the figure.

Fig. 42.

The Florence flask is heated by means of a spirit-lamp, or a special kind of gas-light, called a Bunsen's burner. Soon the white chlorate melts, and a gas is given off which drives down the water in the inverted jar. When we have filled the jar with this gas, we can collect it by putting a piece of ground glass over the mouth of the jar and then removing it from the trough. Now put a burning taper in the jar of oxygen gas. *It bursts into* a most brilliant flame. Or

a red-hot match put into the jar at once bursts into flame again.

Collect another jar of oxygen. Take a piece of iron wire coiled in the shape of a cork-screw, as in fig. 43, tie a small piece of a match on to its end, light the match, and put the wire with the burning match attached into the jar of oxygen. The match burns very brightly, and,

Fig. 43.

strange to say, the iron follows suit, burning and producing most beautiful sparks, the substance formed dropping to the bottom of the jar, where, if it is examined, it will be found to be identical with iron rust.

Many other very pretty experiments can be performed with oxygen, and it possesses the advantage of being a gas perfectly safe to ex-

periment with. But what we have described will suffice to show that oxygen is a gas, in which substances burn with great eagerness, and with a most brilliant flame.

## LESSON 31.

Perhaps you will ask how it is that substances do not burn as rapidly and readily in air as they do in oxygen. Charcoal, for instance, burns in air without flame or sparks. There is only a dull red heat. But in oxygen charcoal burns with the production of most brilliant sparks. The answer is found in the character of the nitrogen forming four-fifths of the air. You remember a light would not burn in it at all. A light burns very rapidly and greedily in oxygen. The nitrogen serves as a *diluting agent*, and prevents the oxygen burning up substances too completely or too rapidly. Imagine if the air were all oxygen what would be the result!

We saw that iron wire was easily burnt in oxygen. And similarly in our fireplaces after all the coal was exhausted, the iron ranges would be burnt up.

You know that when coal is burnt most of the products of burning escape up the chimney, and only a small part are left behind as ashes. But when iron is burnt no gases are produced,—nothing but rust; and so our fireplaces would very soon get choked up.

Again, we shall find later on that a combus-

tion or burning by means of oxygen is going on in our own bodies; and if the air were composed only of oxygen, the burning up of the food and tissues of our bodies would occur very rapidly, and our lives would be much shorter than they are. The presence in air, therefore, of four times as much nitrogen as oxygen is a most wise provision, and one which is quite essential to our well-being.

I want you to note particularly that the nitrogen and oxygen in air are not chemically combined so as to form a third gas different from either nitrogen or oxygen; but the properties of air are, so to speak, intermediate between those of nitrogen and oxygen. It is therefore a mechanical mixture of these two gases. That this is so is proved by the fact that if we mix nitrogen and oxygen in the proportion of four parts of the former to one part of the latter, an air is formed in which life can be supported; and yet no heat is evolved, as is invariably the case when a chemical compound is produced.

We can also prove the same thing in another way. You know that gases can be dissolved in water. Soda water is a common example of this. In soda water a large quantity of carbonic acid gas is pumped into the water under pressure, and the bubbling you observe when the cork is removed is due to the escape of part of this dissolved gas.

Similarly if you take a jar about a quarter full of water (the rest of the jar of course containing air), and shake up the water, some of the air becomes dissolved in it. Next take this water in which some air has been dissolved ; heat the water ; this drives off the dissolved air. On examining the air which escapes, we find that the proportion of nitrogen to oxygen, instead of being four to one, is a little less than two to one. This is owing to the fact that oxygen dissolves in water much more easily than nitrogen, and so the air driven out from the water by heat contains a much larger proportion of oxygen than ordinary air.

Now if the nitrogen and oxygen had been chemically united, the oxygen could not have been dissolved in greater proportion than the nitrogen, but in the same proportion as the two gases exist in air.

## LESSON 32.

Ordinary air does not consist simply of these two gases. It always contains some water-vapour. The amount of moisture in the air varies greatly at different times. The hotter the air is, the more water it will hold in the form of vapour. Probably you have noticed after a shower on a summer's day how quickly the ground is dry again, and how soon all the little pools of water disappear. But after a

shower of rain on a cold wintry day it takes much longer for the streets to become dry again.

The fact that there is abundant moisture in the air is shown by the fall of dew and rain and snow when the air gets cooled ; but the way in which these are produced has been already explained to you.

I daresay you have often noticed how the window panes in the schoolroom, or still more, the windows of any close small room, become covered with moisture, which shuts out the view of the world outside. This is simply due to the cold glass condensing the water-vapour which always collects in the air breathed by human beings.

Not only is there always a considerable, though varying, amount of water-vapour in the air, but ordinary air, and especially that in towns, always contains some carbonic acid gas, the proportion varying from two to ten parts in ten thousand parts of air. It may be even more than this in rooms where many people are collected, or where many gas-lights are burning. Such air is most injurious, and is sure to cause a headache and sleepiness if breathed for any length of time. It is the great object of open windows and other means of ventilation to get rid of the carbonic acid, and other even worse impurities, which are sure to collect in rooms where many people live.

We shall learn more about carbonic acid and other impurities of air in the following chapters.

**The air is formed of a mixture of four parts of nitrogen with one part of oxygen, with a varying proportion of water-vapour. Oxygen is an acid producer, and a strong supporter of combustion. Nitrogen will not support combustion.**

**The main impurity of air is carbonic acid gas.**

## CHAPTER X.

### THE CHEMISTRY OF WATER.

### LESSON 33.

WE have already had a great deal to say about water, taking it as an example of the properties of liquids (Chapter II.), and as an example of the effect of heat on matter (Chapter V.).

Let us now try and find out its composition. Is it an element or a compound; and if a compound, does it consist of two or more elements? These questions can only be answered by means of various experiments. It is just as impossible to learn chemistry without experiments, as it is to see anything with one's eyes shut.

Take a basin (or pneumatic trough) half full of water, and put on it a piece of the soft metal called sodium, about the size of a pea. This is lighter than water, and will float on the water from side to side, making a peculiar little noise, until it is all dissolved and disappears in the water. Now fill a test tube with water, and invert it, still full of water, over the water in the basin. Attach a piece of fine wire to another bit of sodium, and pass this quickly into the water under the inverted test tube. At once you will notice that the water is driven down the tube by a gas which is ascending from where the sodium floats on the water (fig. 44), until finally the test tube is full of this gas. Now remove the test tube, keeping it with the mouth downwards, apply a light to the mouth, and at once there will be a slight explosion, and a pale blue flame. Thus the sodium has decomposed the water, setting free a gas which is combustible (that is, it burns), and which burns with a pale blue flame; while the sodium at the same time dissolves in the water. Now, suppose we take some of the blue litmus paper which we used in a previous experiment (page 98), and add it to the water in which the sodium has dissolved. No effect is produced. *But if* we take the litmus paper which was

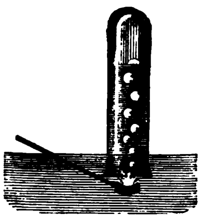

Fig. 44.

turned red by the acid resulting from the burning of phosphorus in air, at once this will be turned blue again by our present solution. Substances which turn red litmus paper blue are called *alkalies*, and the result of the addition of sodium to water is an alkali.

We may represent what happens when sodium is added to water thus :—

Sodium + Water = Hydrogen + Soda.

For it is really pure soda that is dissolved in the water. Why the gas produced in this experiment is called hydrogen we shall soon see.

We have learnt, then, that water is partially composed of an inflammable gas. It is obvious, however, that this is not the only substance contained in water, as ordinary water, whether liquid or in the form of gas, is not inflammable.

## LESSON 34.

We must try and find out by another experiment what besides hydrogen is contained in water.

I daresay you have all seen a galvanic battery. In it is developed, as explained in Lesson 24, a current of electricity, which escapes by two wires fastened to the two ends of the battery. Now let us fix two small platinum plates to the two copper wires coming from the battery, the platinum plates being placed in a

glass vessel nearly full of water, as shown in the figure (fig. 45). Next invert two tubes full of water over the ends of these platinum plates. The water ought to be made acid by means of a very little sulphuric acid (oil of vitriol), so as to conduct the electricity more readily. As soon as the connection is thus made you will notice that the water in the two tubes begins to be pushed down. But soon you will find that the tube connected with what is called the

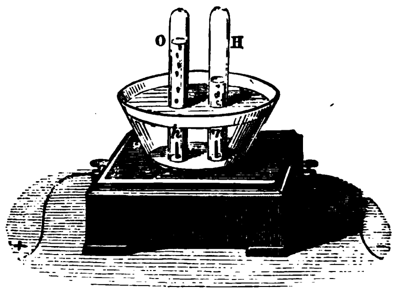


Fig. 45. Decomposition of water by electricity. *h* and *n* the positive and negative platinum plates; O, oxygen; H, hydrogen.

negative end or pole of the battery has twice as much gas in it as the tube connected with the opposite or positive pole, and this proportion is maintained throughout.

Now let us examine the gases in the two tubes. First take the tube containing the largest amount of gas. Keep it still with the mouth downwards, and apply a match to the mouth. At once a slight explosion occurs, and *the gas burns* with a pale blue flame. It is

evidently, therefore, the same gas as was produced when we added sodium to water.

Next take the other tube, and put a burning match into it. The match burns with a most brilliant flame. This gas is evidently oxygen; for we saw that a characteristic property of oxygen is its power to make substances burn much more brightly than they do in air.

The result of this experiment with the galvanic battery is rather startling. It teaches us that water is composed of two gases, hydrogen and oxygen, these gases being in the proportion of two volumes of hydrogen to one of oxygen.

We may prove the same thing by an exactly opposite proceeding. A graduated tube (AB, fig. 46) full of quicksilver is inverted over a basin half full of quicksilver. Two wires, which can be connected with two ends of a galvanic battery, are melted through the tube near its top. Now a certain amount, call it two volumes, of hydrogen gas (obtained by a method we shall describe later on) is passed up the tube, and displaces downwards a certain amount of quicksilver. Next, half as much oxygen is passed up the tube. If the two wires are now connected with the battery, an electric current passes through them, and as they are near together, a spark is produced between the two ends. This *spark* at once makes the hydrogen and

oxygen unite to form water ; and as the water produced is only a drop or two, it occupies

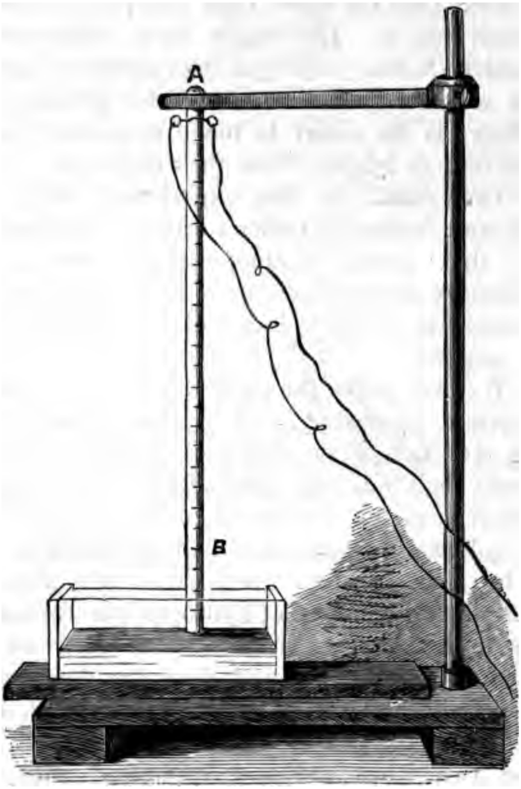


**Fig. 46. Composition of water by the direct union of hydrogen and oxygen.**

scarcely any space, and the quicksilver rushes *up the tube* to fill the vacuum resulting. Thus

by the direct union of hydrogen and oxygen we have made water.

I think now you will admit that the proof of the composition of water is complete. By means of sodium we obtained hydrogen from water, and you will now understand that the burning of the sodium was due to its combining with the oxygen of water. By means of electricity we have both analysed water into hydrogen and oxygen, and then, to complete the proof, have combined these into water again.

## LESSON 35.

If you wish to obtain hydrogen in larger quantities, to study its properties more completely, the best way is to take a Florence flask, with a cork through which two tubes are passed, as in the figure (fig. 47). Into this flask some pieces of zinc are placed, and then sulphuric acid (oil of vitriol), which has been diluted with eight times its bulk of water, is poured down the long tube. At once you will see bubbles of gas rising from the zinc. Now pass a bent tube from the Florence flask, and let its end lie under a tube full of water, which is inverted in a pneumatic trough. The gas coming off from the flask displaces the water in the tube, and speedily fills it. This gas is hydrogen, as you can prove by putting a light to it, taking care to keep the tube with its mouth still down-

wards. Hydrogen is rather a dangerous gas to experiment with, unless great care is exercised. You must be careful to allow some time to elapse after you have added the acid to the zinc before you try and collect the hydrogen, otherwise the air in the flask is not driven out, and is collected in the tube with the hydrogen. This mixture of hydrogen and air is very explosive, and many serious accidents have happened through putting a lighted match to what

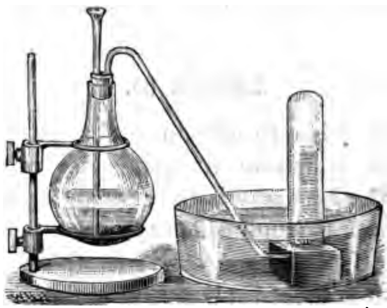

Fig 47. Making hydrogen from zinc and sulphuric acid.

was apparently pure hydrogen, but really a mixture of hydrogen and air.

The usual plan followed in preparing hydrogen is to collect a small test tube full of the gas first, and light this. If it does not explode with a loud noise, but only with a small shrill "pop," it shows that the gas is unmixed with air, and may be safely experimented with.

*I said* just now that the tube containing *hydrogen* ought always to be lighted with the

mouth downwards. The reason for this precaution is, that the gas is so very light, that if the open mouth of the jar were turned upwards, at once all the gas would rush out, and if a light were applied at this time, a violent explosion would result. This extreme lightness of hydrogen may be shown in another way. Collect a jar full of hydrogen, and take another jar which contains nothing but air. Now take the jar, B, containing hydrogen; hold it under

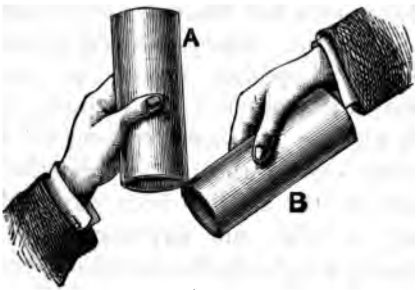


Fig. 48.

the open mouth of the jar, A, containing air, and gradually turn it downwards until the mouths of the two jars meet. Next separate the two jars, and if you apply a light to each, you will find that A contains hydrogen, which burns with a pale blue flame, while B contains nothing but air. We infer, then, that hydrogen is much ighter than air, and tends to ascend; and if you were asked how you could keep hydrogen longest in a jar with one end open, the answer would be to keep the open end downwards.

## LESSON 36.

In a previous experiment we saw that hydrogen and oxygen combine directly to form water. The following experiment, which is much easier to perform, will show the same thing.

The same apparatus will serve as we used for preparing hydrogen from zinc and sulphuric acid, only the tube from which the gas came out is drawn out to a point, instead of being bent down into the basin. Zinc is put in the bottle, then the stopper inserted, and weak sulphuric acid poured down the long tube. Now wait a few minutes until ample time has elapsed for the hydrogen coming off to drive all the air out of the bottle. If you do not wait until all the air has been expelled before applying a light, an explosion will occur. Then apply a light to the drawn-out end of the bent tube. The hydrogen burns with a pale blue flame, and if you hold a dry tumbler over the end of the tube, its interior will soon become covered with condensed water-vapour produced by the burning of hydrogen in the oxygen of air.

But we have not yet stated why this very light and highly inflammable gas we have been experimenting on is called hydrogen.

Oxygen we saw meant acid generator; we *may imagine*, then, that hydrogen is the gene*rator or* producer of something. This something

is water, as we have seen. When hydrogen is burnt in oxygen it produces water; and the word hydrogen means "water generator."

And now we are in a position to answer the questions we started with at the beginning of this chapter. Water is not an element, but a compound, formed of two parts of hydrogen to one of oxygen.

**Sodium splits up water, and proves that one part of it is hydrogen.**

**Alkalies turn red litmus paper blue.**

**The electric current splits up water into hydrogen and oxygen.**

**Hydrogen is a very light and inflammable gas; when burnt in oxygen or air it forms water.**

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## CHAPTER XI.

### DIFFERENT KINDS OF WATER—MODES OF PURIFYING WATER.

### LESSON 37.

WATER, we have seen in the last chapter, is a compound of the two gases hydrogen and oxygen, which, when united, strange to say, form a substance which is liquid at the ordinary temperature.

We shall find instances of even more wonderful transformations than this in chemistry.

But water, in which there is nothing but these two gases, is never found in nature. If it were so, it would be a bad case for the poor fishes. They require free oxygen to breathe; the oxygen which is combined with hydrogen is of no use to them. How is this oxygen supplied? You remember that when we shook up a bottle partly full of water (and the rest air), we found on examining the water afterwards that some of the air had dissolved in it, and that more oxygen had dissolved than nitrogen. This is the oxygen that enables the fishes to breathe. And all water contains some gases dissolved in it. Rain-water, which we are in the habit of regarding as the purest water in nature, is really so in the country, where it has only dissolved some of the pure air, but in descending in towns it has also dissolved many of the organic impurities with which the air is charged.

Now there are various kinds of water, according to the various substances which have accidentally become dissolved in it.

The two main kinds are *fresh* and *salt water.*

*Salt water* you have probably all tasted when bathing, and you know how very salt it is. In every 100 parts it contains 35 parts of solid matter dissolved. Of these 35 parts of solid matter 28 are common salt, like the table

salt you eat. The amount of solid matter in salt water varies very greatly. In the Dead Sea it is so abundant, and the density of the water is in consequence so much increased, that it is difficult for any person to sink in it.

If you were asked what is the easiest water to wash in, you would at once say *soft water*. And this leads us to say that fresh water is either soft or hard. Soft water at once forms a fine lather with soap, whereas with hard water we have to go on rubbing the soap for some time, *until the hardness is neutralised*, before we can get a lather. And, indeed, it is quite possible to estimate the *amount* of hardness by the amount of soap (or better still the amount of a solution of soap of a known strength) that requires to be added to the water before it will form a lather. Such a test as this is known as Clarke's Soap Test.

But water may be hard from two different substances in it; or, in other words, there are two forms of hard water. One is removed by boiling the water; the other is not. London water is generally very hard, but if you boil it, a lather can be at once formed. The water of many springs remains hard however much it is boiled. The first kind of hardness is *temporary*; the second is *permanent*.

## LESSON 38.

*Temporary hardness* of water is due to chalk dissolved from the limestone soil through which the water has percolated. Now chalk is practically insoluble in water. This fact you may prove by pounding a piece of chalk, and then shaking it up in some water. At first a milky mixture is produced, but if you allow this to stand, the chalk settles to the bottom, and the water is left clear above. How comes it, then, that chalk gets dissolved in water sufficiently to make it very hard to wash in? You remember we said that an important impurity of air is carbonic acid gas; and we have seen that a considerable amount of air dissolves in water. Well, with the air carbonic acid is dissolved in water, and this carbonic acid forms a combination with chalk which is soluble in water. You may prove this by taking a large test tube and putting in this a pinch of chalk, and then nearly filling the tube with pure water. After shaking up the mixture, a rather milky-looking liquid is the result, due to the particles of chalk becoming uniformly scattered throughout the liquid, though not dissolved. Now take a piece of narrow tubing, and put one end in your mouth and the other in this milky-looking liquid. Blow into the liquid, and soon it will become clear, or, at any rate, much clearer than before. This is owing to the carbonic acid gas from your lungs having combined with the chalk

and formed a soluble bicarbonate of calcium. Chalk is carbonate of calcium, and is insoluble in water; the addition of carbonic acid to this produces bicarbonate of calcium, which is partially soluble in water. Bicarbonate of calcium is not a stable compound; the carbonic acid gas it has acquired can easily be driven off by heat. Heat the test tube at the end of the last experiment. The liquid in it soon becomes milky again.

The action of heat on this form of hard water explains how it is that our London water is softened by boiling. It also explains the formation of the crust you so commonly see on the inside of kettles and boilers. If you examine your kitchen kettle, probably you will find a thick cake of a hard substance coating it inside, which, though it does not look like chalk, is chemically identical with it. Many boilers get coated with the same material, and then are much more liable to break and burst than under normal conditions. This fact also explains why the water for tea often takes so long to boil. The heat of the fire not only has to get through the iron of the kettle (which it does very easily), but also through this hard cake of chalky material inside.

It is important you should know how the bicarbonate of calcium can be got rid of. At the Kenley and other waterworks in our chalk districts, where the water contains this

bicarbonate, a large quantity of lime (oxide of calcium) is thrown into the reservoirs This combines with the extra equivalent of carbonic acid in bicarbonate of calcium, and produces carbonate of calcium (chalk), which settles to the bottom. At the same time the bicarbonate becomes carbonate of calcium (chalk), which likewise settles. We may represent the action in the form of an equation thus :—

Bicarbonate of Calcium + Oxide and Calcium =
Carbonate of Calcium + Carbonate of Calcium (lime).

## LESSON 39.

*Permanent hardness* of water is due to sulphate of *calcium*, commonly known as gypsum. Chalk is carbonate of *calcium* ; gypsum, sulphate of calcium. But we shall be better able to understand these names later on. Not more than one part of gypsum will dissolve in four hundred parts of water, but this small proportion is quite sufficient to make the water unpleasantly hard. And unfortunately very little of the gypsum is got rid of by boiling ; hence this form of hard water is said to be permanently so.

Solid gypsum contains some water bound up in its substance. If it is heated, this water is driven off, and then the powder well known as Plaster-of-Paris is produced. Plaster-of-Paris *when moistened* combines again with water, and *then sets into* a hard, solid substance. It can

be moulded when soft into any shape, and as it speedily solidifies in the shape given to it, it is largely used for making casts and moulds.

Hardness is a great drawback to any water, but there are other conditions which are much more harmful to health than this.

Sometimes water becomes contaminated from sewers. Owing to some leakage in pipes or drains, the two become mixed ; or even when the actual liquid or solid contents of sewers do not get into the water, the sewer gases do, and these may do just as much harm. Very often fevers, and especially typhoid fever, result from drinking water which has been thus contaminated. The only safe way to get rid of the possible poison is to boil the water before drinking.

Owing to the water having to pass through lead pipes, it sometimes happens that a portion of the lead gets dissolved in the water. This has frequently produced symptoms of poisoning, the cause of which has not been discovered for a long time.

Some forms of water dissolve lead much more readily than others. Hard waters, as a rule, do not dissolve the lead unless there is considerable free carbonic acid in the water, but soft waters act on it readily.

Such are the main impurities of water. How are we to get rid of them ? There is a class of *impurities* we have not mentioned yet—namely,

those which are suspended in the water, just as we found chalk was, but not dissolved. Such impurities can be got rid of by *Filtration.* There are various kinds of filters. I daresay you have seen in connection with the water-works supplying London or some large town huge beds of beautifully clean and fine sand. The water, before being allowed to enter the pipes on its way to its ultimate destination, is filtered through these beds of sand, and so every particle of solid matter is separated from it. The filters you see in use at home are generally made of charcoal. This charcoal has the power of holding in its meshes a large amount of air, and so it comes to pass that not only does the charcoal separate solid particles from the water, but if the water is ill-smelling, it makes it sweeter, owing to the oxygen (from the air) which it contains in its meshes. But still it remains true that the main use of filtering is to separate solid impurities.

## LESSON 40.

The class of impurities which are dissolved in the water can only be got rid of by *Distillation.* This process may be effected on a small scale by an apparatus like that sketched in fig. 49. The retort, *a*, is partially filled with impure water (say salt water), while the other end of the retort is inserted into the neck of the *Florence flask*, *b.* The retort is heated by a

spirit or gas lamp, and as the steam comes off it gets into the Florence flask, and there is speedily condensed by the help of the cold water in the basin in which the flask is placed. When all the water has been boiled away from the retort, at its bottom will be found the salts which give sea water its character; while the water at the other end of the apparatus, though

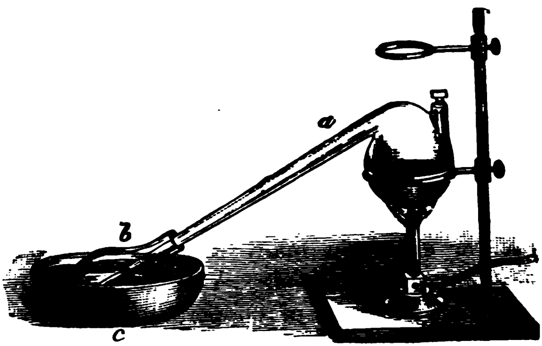


Fig. 49. Simple Distilling Apparatus. *a*, retort; *b*, a flask placed in basin of cold water.

rather flat, is perfectly pure. So, you see, the solid impurities are left behind, while the steam passes over and forms pure water. Suppose you were becalmed on board ship in mid-ocean and without a supply of fresh water, this knowledge of how to obtain pure water from sea water would be of vital importance. Similarly other solid impurities can always be removed *by this* process of distillation.

Distillation is constantly occurring on a grand scale in nature. The heat of the sun's rays evaporates the water from the ocean (playing in an infinitely more perfect way the part of the spirit-lamp in the last experiment). The ocean itself is a grand retort, while the water thus evaporated is condensed in the form of clouds, and descends as rain or snow or dew.

Water is one of the most universally diffused substances; it exists everywhere; in the air, as water itself; entering into the formation of very many solid substances, and forming a very large proportion of the substance of plants and animals. Strange as it may seem, four out of every five parts of the human body are composed of water.

Water exists in many solid substances, as *water of crystallization.* You all know blue vitriol, or sulphate of copper, as it is more correctly named. If you heat this strongly in a test tube, some steam will be given off which may condense on the higher part of the tube, and the large blue crystals have become a white powder. And this remarkable change is owing to the simple loss of water. It is chiefly salts which enter into this union with water to form crystals, and when the water is driven off from them they become powders. The forms which different crystals take are very beautiful and well worthy of study; and yet these crystals could not exist without water!

**Water in nature always contains some air dissolved.**

**Water is either fresh or salt.**

**Fresh water is hard or soft.**

**Hard water is temporarily so or permanently so.**

**Temporary hardness is due to chalk, permanent hardness to gypsum.**

**Filtration gets rid of suspended impurities, distillation of dissolved impurities.**

**Water in certain solid substances enables them to assume exact crystalline shapes.**

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# CHAPTER XII.

## CHEMISTRY OF CARBON AND ITS COMPOUNDS.

### LESSON 41.

HITHERTO we have considered air and water, a gas and a liquid. Let us now turn to carbon, which is a solid body, and familiar to you all, at least in one form—namely, that of charcoal. For charcoal is mainly composed of this element carbon. It is true that common charcoal generally

contains certain salts derived from wood or bone, but these can be dissolved out by an acid, and then nothing but the element carbon remains. One form of charcoal is made from wood, another from bones. In each case the carbon is made by burning the wood or the bones in a closed furnace, so as not to admit much air; for if much air be admitted, the oxygen in it combines with the carbon, and forms a gas, carbonic acid, instead of solid charcoal. Charcoal is made on a small scale every time we light a match; the blackened residue after burning is charcoal.

What are the properties of charcoal? If you put a piece of it into water, it floats on the surface; but this is owing to the porous nature of stick charcoal, for if you powder it carefully, it will then sink in water. The porous character of charcoal enables it to absorb a large quantity of various gases, and especially oxygen. When charcoal is placed in rooms where there is a bad smell, it destroys the smell; this power is probably really due to the oxygen contained in the pores of the charcoal. You will observe that the charcoal, however much you shake it up with water, does not dissolve in it.

Charcoal is not the only form in which the element carbon exists. There are two other important varieties of it, namely, graphite and diamond.

Graphite is the same thing as you know

under the name of blacklead, though this name is certainly a misnomer, as there is no lead in it. It is much harder than charcoal, but not so hard as diamond. It forms small six-sided plates, which occur naturally in Borrowdale in Cumberland, and elsewhere. You know it is used for polishing the iron-work in fireplaces, and for making lead pencils, as well as some other purposes.

Diamond is the same thing as charcoal, so

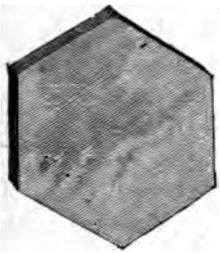

Fig. 50. Six-sided Scale of Graphite.

Fig. 51. Octahedral Crystal of Diamond.

far as its chemical composition is concerned, but yet how different it looks! It is beautifully clear, it sparkles in the light, and refracts all the colours of the rainbow, it is so hard that you can cut glass with it, and yet it is chemically the same thing as the dirty charcoal. You may prove this by burning a small diamond in oxygen gas, or rather, as the experiment would be an expensive one, you will probably accept the statement that when charcoal and diamond are burnt in oxygen they

each produce the same gas (carbonic acid); and you know that if two substances both form the same gas when burnt, they must themselves be chemically identical with each other; just as you know that if

$x + 5 = 8$ and $y + 5 = 8$, $x$ and $y$ are both the same—viz., 3.

## LESSON 42.

Soot is another form of carbon, which is formed in the fireplace, when the supply of air to the burning coal is incomplete. It is formed from coal, just in the same way as charcoal is formed from wood if there is not sufficient air present to burn the wood completely. Coal is really a blackened form of wood; and soot is practically identical with ordinary wood charcoal.

In London and many large towns the fogs are loaded with soot, and are the cause of many serious diseases. It would be a great advantage if every house were supplied with ranges in which the coal could be completely burnt, and so no soot be formed.

I daresay you have noticed that with a fire in which the coals are all red-hot, and no soot is escaping up the chimney, much more heat is given out than with a fire which emits smoke, even though there be a bright blaze *as well.* The soot in burning produces heat,

and so it is really more economical to have a "smoke-consuming" fireplace.

Lampblack is a kind of charcoal which is made by letting the smoke from burning resin or pitch pass into a chamber lined with leather. The lampblack collects on the sides of the chamber. It is much used in painting, and in making the kind of ink called "printers' ink," with which this book is printed. This ink is different from ordinary writing ink, which is usually formed by the combination of tannin and sulphate of iron.

Carbon is contained not only in the substances we have named, but also in many others in which its existence is not so evident. That piece of chalk with which your teacher writes on the black-board contains a considerable proportion of carbon, and so does ordinary washing soda. But in these cases it is combined with other elements, and it would be very difficult to separate it from them.

We have seen that charcoal is obtained by burning wood or bones. It is evident, then, that it enters into the composition of plants and animals. You every day see the proof of its existence in bread. You know that when a piece of bread is toasted too much, it goes black, or, in other words, charcoal is separated from the bread. Similarly a piece of meat if overdone forms charcoal.

Suppose you get some strong sulphuric acid

(oil of vitriol) and pour about a tea-spoonful carefully on two or three lumps of sugar placed in a cup. The sugar at once turns black, and, in fact, forms charcoal. The sulphuric acid acts by taking away water from sugar, and when water is gone nothing but charcoal remains. Strange as it may seem, sugar can be analysed into nothing but charcoal and water.

The fact that carbon is contained in all plants and animals will show how important it is that we should thoroughly understand its properties.

## LESSON 43.

Now when charcoal or any other form of carbon is burnt in a jar of oxygen gas, the carbon disappears, and on examining the jar we find in it a heavy colourless gas without any smell, very different in its properties from oxygen, but formed by the union of the solid carbon with oxygen. Insert a burning taper in the jar. Instead of burning brightly, as it would have done in oxygen, it goes out. Next pour a little water into the jar, and shake it up well. A great part of the carbonic acid dissolves in the water, and if you now put a piece of blue litmus paper into the solution, it is turned red for a short time, proving that carbonic acid has a right to the name of *Acid.*

Suppose you take another jar in which you have burned charcoal, and pour into it some

clear lime-water. This is at once turned milky. The milkiness is due to chalk, for lime-water and carbonic acid together form chalk, which, after a time, will settle to the bottom of the jar.

You will remember that nitrogen puts out a taper, but it does not turn lime-water milky, nor does it turn blue litmus paper red; so it can be easily distinguished from carbonic acid.

Carbonic acid gas can be best prepared by

Fig. 52. Preparation of Carbonic Acid Gas.

taking fragments of marble or chalk (which are chemically identical), putting them into a bottle, as shown in fig. 52, and pouring on them some hydrochloric acid, or spirits of salt. The gas which bubbles from the chalk can be collected by simply putting the long end of the bent tube into an open jar or bottle, for the gas is so heavy that it at once sinks to the bottom. That the gas thus obtained is the same as that produced by the burning of carbon in air or oxygen can be proved by its effect on a burn-

ing taper, on lime-water, and on moistened blue litmus paper.

You have seen that a taper will not burn in carbonic acid. A useful application of this fact has been made in the shape of an apparatus for putting out large fires. A large quantity is forced into a small reservoir by means of a special pump. To this reservoir a hose with a

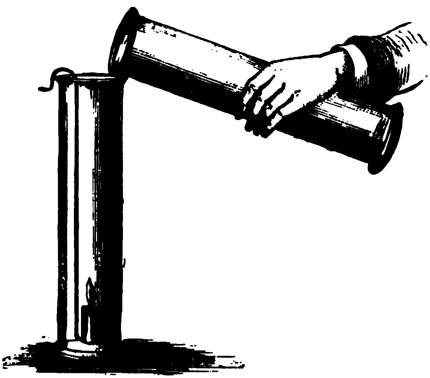

Fig. 53.

stopcock is attached. When the stopcock is turned the gas rushes out with great force, and any fire in its neighbourhood is at once extinguished. This plan has been found useful in one or two cases of fire in coal mines. The carbonic acid is a heavy gas, and naturally falls to the deeper parts of the mine, where the fire is situated. An experiment which explains itself in illustration of this fact is depicted in fig. 53.

Not only are flames of various kinds extinguished by carbonic acid gas, but no animal can live in it. This has been sadly proved over and over again, as in the lime-kilns already mentioned. Limestone is, like marble, chemically the same thing as chalk. In the kiln it is heated to a red heat ; by this means carbonic acid is driven off from it, which tends to accumulate around the kiln. It possesses no warning smell, and so many who have thoughtlessly gone to sleep in front of the fires have been poisoned.

Perhaps you have heard of workmen who have gone down some deep well, and on reaching the bottom have, unless very speedily rescued, become unconscious and died. Here, again, the noxious material is carbonic acid gas. This is produced in the well by the decomposition of leaves and other vegetable matters, and being heavier than ordinary air, it accumulates at the bottom. The way to avoid such accidents as this would be for the workman to descend with a candle held well below the level of his head. If the candle-light gets smaller, and shows signs of going out, it is unsafe to proceed further.

The carbonic acid which thus accumulates in wells may be got rid of by throwing some lime into the water. The lime combines with the carbonic acid to form chalk. Some of the chalk, however, dissolves in the water (if there

is an excess of carbonic acid), and so the water is made hard. A better plan is to throw down into the well a bundle of burning shavings. These heat the carbonic acid at the bottom of the well, and so make it lighter. It, therefore, ascends, and escapes from the well with the rest of the hot air produced by the burning of the shavings.

## LESSON 44.

Carbonic acid is not the only compound produced by the union of carbon and oxygen. There is another in which the proportion of oxygen is just half as much as in carbonic acid. This is called carbon monoxide (which means a compound of carbon with one part of oxygen), just as carbonic acid is sometimes called carbon dioxide (that is, a compound of carbon with two parts of oxygen). You see its formation every day in the fire. When the coals have become red-hot, there is often a pale blue flame at the top of the fire. The coal at the lowest part of the fire combines with the oxygen of the air to form carbon dioxide ; this, as it passes up through the middle layers of coal, meets with more carbon, which reduces it to carbon monoxide, and then the carbon monoxide, appearing at the top of the fire, combines again with the *oxygen of* the air, burning with a blue flame *to produce* carbon dioxide.

We may represent this double action in the form of an equation.

Let C stand for Carbon, O for Oxygen, and $O_2$ for two parts of Oxygen.

$$\text{Then} \begin{cases} (1)\ C + O_2 = CO_2. \\ (2)\ CO_2 + C = 2\ CO. \\ (3)\ 2\ CO + O_2 = 2\ CO_2. \end{cases}$$

Carbon forms compounds not only with oxygen, but also with hydrogen and nitrogen.

You also remember that two parts of hydrogen combine with one of oxygen to form water; and we have just learnt that carbon combines with two parts of oxygen to form carbonic acid. We should expect, then, that one part of carbon would combine with four parts of hydrogen, and so it does, though not directly.

This compound of carbon and hydrogen is commonly known as marsh gas. It is often found in stagnant pools. If you stir up the bottom of a stagnant pool, sometimes bubbles of gas will ascend, which, when a lighted match is put to them, will burn on the water. Very likely this phenomenon has given rise to the stories about "Will-o'-the-wisp." The bubbles of gas can be easily collected in the manner shown in the illustration (fig. 54).

Marsh gas is also given off sometimes from the coal in mines. It is then known as "fire-damp," and is very explosive. When an explosion takes place, the carbon and hydrogen *both combine* with the oxygen of air,—the

carbon to form carbonic acid, the hydrogen to form water; these together form what the miners very significantly call "choke-damp," and this is even more dangerous than the original fire-damp.

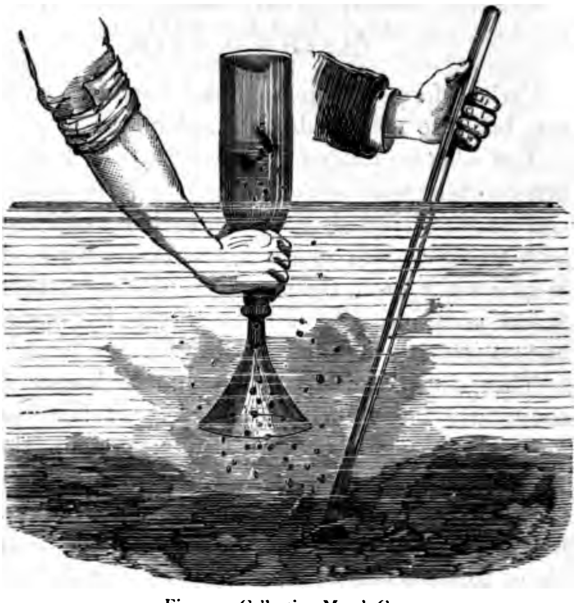

Fig. 54. Collecting Marsh Gas.

We may represent what takes place in the combustion or explosion of marsh gas thus, hydrogen being represented by H, carbon by C, and oxygen by O:—

Marsh Gas ($CH_4$) + ($2O_2$) = Carbonic Acid ($CO_2$) + two parts of Water ($2\ H_2O$).

*Carbon* combines with the two elements

hydrogen and nitrogen to form prussic acid, the most deadly poison known.

**Carbon exists in three chief forms, —charcoal, graphite, and diamond. It exists in all plants and animals.**

**Carbon combines with oxygen to form carbonic acid gas, which does not support combustion, and turns lime-water milky.**

**With half the same amount of oxygen it forms carbon monoxide.**

**Combined with hydrogen, it forms marsh gas; combined with hydrogen and nitrogen, it forms prussic acid.**

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## CHAPTER XIII.

### NITRIC ACID, AMMONIA, CHLORINE, PHOSPHORUS, ETC.

### LESSON 45.

In Chapter X. we studied the properties of nitrogen, and examined air, finding it to be a mixture of nitrogen and oxygen. But nitrogen also forms a chemical compound with oxygen, which, when dissolved in water, is known as *nitric acid.* This is not the usual way of pre-

paring nitric acid. It is generally made with a similar apparatus to that used in the distillation of water (see fig. 49). Ordinary saltpetre is taken, and sulphuric acid is poured on it in a retort. The retort is then heated, and the nitric acid comes off as a gas, which is condensed in the flask at the other end of the apparatus by keeping a stream of cold water running on the outside of the flask. The acid thus obtained is a yellowish liquid giving off fumes, and turning blue litmus paper violently red. It dissolves many of the metals. If you pour some nitric acid on a farthing, red fumes (due to the setting free of a compound of oxygen and nitrogen) are produced, and the farthing is gradually dissolved, a green salt called nitrate of copper being produced.

Nitrogen and hydrogen unite together, in the proportion of one of nitrogen to three of hydrogen, to form a compound with which you are very familiar under the name of *ammonia.* They cannot be made to unite directly, but are obtained from compounds containing the two elements. Most vegetable and animal matters when heated will give off ammonia. Thus, if you heat a piece of meat or a pea in a test tube with a little quicklime, at once a pungent smell is perceived, quite characteristic of ammonia. When coal is heated one of the gases produced *is ammonia*; horns and the chippings of hides *similarly* give off ammonia when heated. You

know that when feathers or hairs are burnt there is a pungent smell; this is due to ammonia.

Ammonia is usually prepared by taking sal-ammoniac and heating it in a flask with quick-lime. A flask like that used in preparing oxygen will serve very well. The ammonia is carried into water by means of a bent tube, and the water sucks it up very greedily; in other words, ammonia is very soluble in water.

If you put a piece of red litmus paper into the solution of ammonia, it is at once turned blue. Now substances which turn red litmus paper blue are called *alkalies*, and it is found that they have directly opposite properties to *acids*, which you will remember turn blue litmus paper red. Alkalies have a soapy taste; acids taste sour. When acids and alkalies are brought together they form *salts*, which commonly have no action at all on litmus paper, though this is not always the case. Thus acids and alkalies are said to neutralise each other.

Ammonia, then, we see, is a gas possessing a very pungent odour, having an alkaline reaction, and very soluble in water. It combines with carbonic acid to form a salt, commonly known as "smelling-salts," which still possesses a pungent odour.

## LESSON 46.

It will be convenient to review at this point *the properties* of the four elementary bodies we

have hitherto examined. Three of them are gases—oxygen, nitrogen, and hydrogen; the fourth, carbon, is a solid. Oxygen is the great supporter of combustion, but does not itself burn; hydrogen burns, but does not support

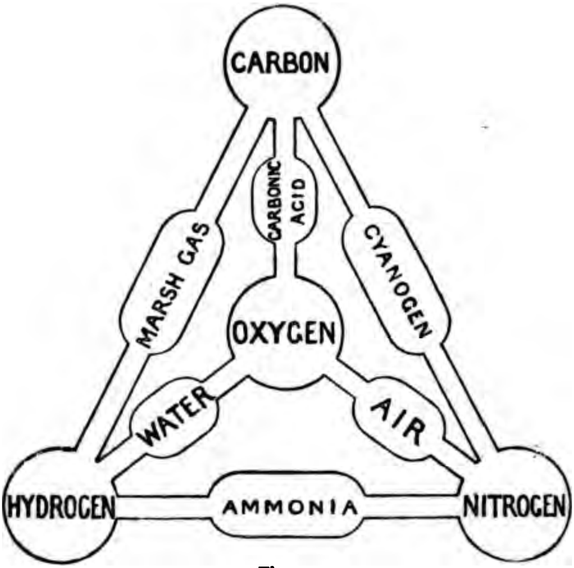


Fig. 55.

combustion; nitrogen neither burns nor supports combustion; carbon burns, but of course nothing will burn in solid carbon, and if it could be made a vapour, still it would not support combustion. Thus carbon and hydrogen are *the elements* that are capable of burning, and *it is oxygen* which burns them; while nitrogen

is a sort of diluting agent, preventing the burning being too rapid or too fierce.

We have described many of the compounds which these four elements form with each other. The accompanying diagram (fig. 55) will show at a glance how far these elements combine with each other. The three gases form three different substances among themselves: hydrogen and oxygen form water; nitrogen and hydrogen form ammonia; while nitrogen and oxygen form the mixture (not the compound) air. Carbon unites with each of the three gases: with oxygen to form carbonic acid; with hydrogen to form marsh gas; and with nitrogen to form cyanogen, which, with hydrogen, forms prussic acid.

We must now pass on to study in less detail a few other substances. You all are familiar with common table-salt. Perhaps you will not recognise it under the name of *chloride of sodium.* It is really a compound of a metal, sodium, and a gas, chlorine. Sodium, you will remember, was able to decompose water, setting free hydrogen, while the sodium combined with oxygen, and dissolved in water to form the alkaline soda. Chlorine is a gas which may be obtained from common salt by heating it with sulphuric acid, and a substance called black oxide of manganese. It is a greenish-yellow gas, and has a most disagreeable suffocating smell. Its most important property is its

power to bleach vegetable substances, but only when they are moistened. Put a living plant in a jar containing chlorine, and it will be at once turned white. Chlorine will not bleach mineral colours. You may prove this by putting an old envelope, which has been soaked in water, in a jar of chlorine gas. The written address will be bleached, but the postmark (made by printers' ink, which you will remember is chiefly lampblack) remains quite unaffected.

## LESSON 47.

*Phosphorus* is not found as such in nature, but chiefly in combination with the metal calcium and oxygen as phosphate of calcium. It is prepared from phosphate of calcium by a complicated process. It is a soft yellow solid, which very easily takes fire, and ought never to be handled. We saw in the chapter on air that it combines with the oxygen of air, forming oxide of phosphorus, and that this dissolves in water, forming phosphoric acid.

Phosphorus + Oxygen = Oxide of Phosphorus.
Oxide of Phosphorus + Water = Phosphoric Acid.

Phosphorus taking fire so readily, is useful for making matches, which are lighted by friction on a rough surface. The end of the match is first sprinkled with sulphur, and then tipped with a composition containing glue, phosphorus, and chlorate of potassium. The fumes

produced by the slow burning of phosphorus in air are extremely noxious, and workmen engaged in making ordinary matches are liable to a terrible disease of the bones of the face. Fortunately a variety of phosphorus has been discovered which does not burn spontaneously in air, nor give off any corrosive fumes. This modified phosphorus is prepared by heating the yellow and waxy phosphorus to a high temperature, in an atmosphere containing no free oxygen (such as carbonic acid). The phosphorus then becomes red and powdery, and can be heated to 500° Fahr. without burning, though if very slightly rubbed with chlorate of potassium, it detonates. "Safety matches" are now made with this variety of phosphorus, and so the poor work-people are saved from the danger of being poisoned, while we have the additional advantage of matches that are very safe, for they will only light on the box. The grit of the match-box is mixed with red phosphorus, and the match-head is tipped with a composition containing chlorate of potassium; but as it contains no phosphorus, it does not ignite if rubbed against an ordinary rough surface.

Perhaps you will ask what sets the phosphorus on fire when a match is struck. It is the friction of the match against the box in the case of safety matches, or of the match against any rough surface in the case of ordinary *matches.* The friction generates enough heat

to fire the match. The same principle is seen in the method of lighting fires that was in vogue before matches were invented. A flint, steel, and tinder-box were used. When the steel was struck sharply by the flint a spark was produced, and this spark was made to fall on the tinder in a box, the tinder being a

Fig. 56. TINDER BOX, FLINT AND STEEL, AND OLD-FASHIONED BRIMSTONE-TIPPED MATCHES.

piece of rag which has been soaked in saltpetre and dried. The tinder then began to smoulder, and from it a flame could be obtained by applying a piece of wood tipped with sulphur.

The spark in this case is really a little fragment of iron torn off, and made so hot by the stroke of the flint that it combines with the oxygen of the air to form oxide of iron, which

you are perhaps more familiar with under the name of rust.

## LESSON 48.

*Sulphur.* You are doubtless familiar with this, both as "flowers of sulphur" and as "stick-sulphur." I daresay you have noticed that a lump of sulphur is often put in the water intended for dogs to drink ; but this is quite useless, as sulphur does not dissolve in water. In order that it may be swallowed, it must be finely powdered, well mixed with the water, and drunk immediately, as it soon sinks to the bottom of the water.

If ordinary sulphur be melted in a spoon, and then allowed to cool slowly, it forms needle-shaped crystals (fig. 57) ; if, after melting, it is poured into water, we obtain a tenacious form of sulphur, which can be stretched like a piece of india-rubber.

Fig. 57. NEEDLE-SHAPED CRYSTALS OF SULPHUR.

Sulphur, when burnt in air, produces a suffocating gas, known as sulphur dioxide. We may represent the reaction as follows, S representing one part of sulphur, and $O_2$ two parts of oxygen :—

$$S + O_2 = S O_2.$$

Sulphur dioxide can be made to combine

with another part of oxygen, producing sulphur trioxide. Thus :—

$$SO_2 + O = SO_3.$$

This sulphur trioxide when dissolved in water produces sulphuric acid, commonly known as oil of vitriol. Sulphuric acid is a most important liquid, being used in the preparation of many substances.

We have in the preceding pages used names that may confuse you. Let us explain the most difficult of them. You have learnt that acids and alkalies neutralize each other, and form salts. Thus by the addition of quicklime to sulphuric acid we get sulphate of calcium. We may represent it thus :—

$$\text{QUICKLIME}\left\{\begin{array}{l}\text{Calcium}\\ \text{Oxygen}\end{array}\right\} + \text{SULPHURIC ACID}\left\{\begin{array}{l}\text{Hydrogen}\\ \text{Sulphur}\\ \text{Oxygen}\end{array}\right\}$$

$$= \text{WATER}\left\{\begin{array}{l}\text{Hydrogen}\\ \text{Oxygen}\end{array}\right\} + \text{CALCIUM SULPHATE}\left\{\begin{array}{l}\text{Calcium}\\ \text{Sulphur}\\ \text{Oxygen.}\end{array}\right.$$

You see, then, that acids become salts by the substitution of a metal for the hydrogen of the acid. The quicklime and the sulphuric acid are both altered in their composition.

## LESSON 49.

You remember we prepared nitric acid by the addition of sulphuric acid to saltpetre. We may represent the change thus :—

$$\textit{SALTPETRE}\left\{\begin{array}{l}\text{Potassium}\\ \text{Nitrogen}\\ \text{Oxygen}\end{array}\right\} + \text{SULPHURIC ACID}\left\{\begin{array}{l}\text{Hydrogen}\\ \text{Sulphur}\\ \text{Oxygen}\end{array}\right\}$$

$$= \text{Nitric Acid} \left\{ \begin{array}{l} \text{Hydrogen} \\ \text{Nitrogen} \\ \text{Oxygen} \end{array} \right\} + \begin{array}{c} \text{Potassium} \\ \text{Sulphate} \end{array} \left\{ \begin{array}{l} \text{Potassium} \\ \text{Sulphur} \\ \text{Oxygen.} \end{array} \right.$$

Here, again, both the saltpetre and the sulphuric acid are altered in composition. In other words, there is a double decomposition. The hydrogen of the sulphuric acid drives out the potassium from saltpetre, taking its place, while the potassium takes the place of the hydrogen of sulphuric acid, changing it to potassium sulphate.

A *sulphate*, then, is sulphuric acid, in which the hydrogen is replaced by a metal, and a *nitrate* is nitric acid, in which the hydrogen is replaced by a metal. Similarly, a *chloride* is hydrochloric acid, in which the hydrogen is replaced by a metal. Thus suppose we take some carbonate of soda and pour on it a little hydrochloric acid. At once a number of bubbles appear, due to the evolution of the carbonic acid, and the carbonate of soda becomes common table-salt. Thus:—

$$\begin{array}{c} \text{Carbonate of} \\ \text{Sodium} \end{array} \left\{ \begin{array}{l} \text{Sodium} \\ \text{Carbon} \\ \text{Oxygen} \end{array} \right\} + \begin{array}{c} \text{Hydrochloric} \\ \text{Acid} \end{array} \left\{ \begin{array}{l} \text{Hydrogen} \\ \text{Chlorine} \end{array} \right\}$$

$$= \begin{array}{c} \text{Carbonic} \\ \text{Acid} \end{array} \left\{ \begin{array}{l} \text{Carbon} \\ \text{Oxygen} \end{array} \right\} + \text{Water} \left\{ \begin{array}{l} \text{Hydrogen} \\ \text{Oxygen} \end{array} \right\}$$

$$+ \text{Chloride of Sodium} \left\{ \begin{array}{l} \text{Sodium} \\ \text{Chlorine.} \end{array} \right.$$

We have several times used the word *oxide*, and I think you will begin to appreciate how

very important oxygen is in nature. Nearly everything combines with it. The compound produced by the combination of oxygen with any other element is called an oxide.

You will remember that when hydrogen burnt in air (that is, in the oxygen of air) water was produced. Water, then, may be called oxide of hydrogen. Similarly, when sulphur, or phosphorus, or carbon is burnt in air, oxides of these substances are produced. In the case of carbon, there are two oxides, carbon monoxide and carbon dioxide, according as the carbon combines with one or two parts of oxygen.

All the oxides yet named, with the exception of water, when dissolved in water, turn blue litmus paper red. The oxides which have this action on litmus paper are all non-metallic oxides.

If we take a piece of the metal sodium and put it on water, it combines with the oxygen of water, and then dissolves in the rest of the water. This metallic oxide, however, does not turn blue litmus red, but turns red litmus blue. And this is true of all metallic oxides that have any action on litmus at all. Oxide of iron (rust) has no action on litmus, but this is because it is insoluble in water. Lime dissolves to some extent in water, and so turns red litmus blue.

We may therefore classify oxides, which are

soluble in water, under two heads—1st, non-metallic acidifying oxides ; and 2nd, metallic alkaline oxides.

Now the non-metallic oxides when dissolved in water form the most important *acids* ; and metallic oxides, whether they be alkaline or not, all combine with these acids to form *salts*. Thus :—

$$\begin{matrix}\text{RUST OR}\\ \text{IRON OXIDE}\end{matrix}\left\{\begin{matrix}\text{Iron}\\ \\ \text{Oxygen}\end{matrix}\right\} + \text{SULPHURIC ACID}\left\{\begin{matrix}\text{Hydrogen}\\ \text{Sulphur}\\ \text{Oxygen}\end{matrix}\right\}$$

$$= \text{WATER}\left\{\begin{matrix}\text{Hydrogen}\\ \\ \text{Oxygen}\end{matrix}\right\} + \text{IRON SULPHATE}\left\{\begin{matrix}\text{Iron}\\ \text{Sulphur}\\ \text{Oxygen.}\end{matrix}\right.$$

Nitric acid is an oxide of nitrogen combined with water.

Ammonia is a pungent alkaline gas, which may be obtained by burning animal substances.

Chlorine is a greenish gas, of a suffocating odour, and a powerful bleacher.

Red phosphorus is much safer than yellow phosphorus.

Sulphuric acid is an oxide of sulphur combined with water.

Non-metallic and metallic oxides have very different properties.

# CHAPTER XIV.

## FATS, SUGAR, STARCH, CELLULOSE, ETC.

### LESSON 50.

WE have studied especially the four elements carbon, hydrogen, oxygen, and nitrogen, and have seen how they form various combinations among one another. But the combinations we have hitherto examined are not the only ones found. There are others much more complicated contained in plants and animals, which it is necessary we should know something about.

*Fats* and *oils* are found in both plants and animals, the only difference between them being that a fat is solid and an oil is liquid at the ordinary temperatures of the air. Many of these fats and oils you are familiar with. From vegetables we have olive oil, almond oil, colza oil, palm oil, castor oil, linseed oil, and cocoa-nut oil; from animals we have cod-liver oil, lard, which is the fat of the pig, suet, which is the fat of the sheep or ox, sperm oil, spermaceti from the whale, bees'-wax, and butter.

Oils are not simple compounds, but mixtures of at least three compound bodies in various proportions, called stearin, palmitin, and olein.

The composition of stearin is represented by *this formula* :—

$$\left.\begin{matrix} C_3H_5 \\ (C_{18}H_{35}O)_3 \end{matrix}\right\} O_3,$$

C, H, and O representing carbon, hydrogen, and oxygen respectively, and the figures after them representing the number of atoms (that is, very minute particles) of each contained in one part of stearin.

Palmitin and olein are very closely allied in composition to stearin. The compounds examined in the former chapters are much simpler in composition than stearin. Thus carbonic acid is represented by the formula $CO_2$. This means that the molecule of carbonic acid consists of one atom of carbon and two of oxygen. By *molecule* we mean the smallest possible particle of a compound that can exist by itself; by *atoms* we mean the several parts (two or more) of which this molecule is made up. In carbonic acid, then, the molecule consists of three atoms combined together. But in the stearin molecule, if you add up, you will find there are sixty-seven atoms. Hence the greater complexity of the bodies we are now considering.

If you shake up in a bottle some oil and water, they will separate when allowed to stand; but if a solution of caustic soda is shaken up with an oil, a milky liquid is formed, and the oil and water do not separate out on standing. If you boil the milky liquid formed by adding an alkaline solution to an oil, it becomes clear, and on shaking up it produces a lather. In *fact, soap* has thus been made. At the same time

as soap is formed, *glycerine* is driven out by the alkali from the oil or fat used. How shall we separate the glycerine from the soap? Well, it is found that a strong solution of common salt causes the soap to curdle and rise to the top, and the liquid containing glycerine can be drawn off by a tap below. We may represent the formation of soap thus :—

Stearin + caustic soda = stearate of soda (soap) + glycerine.

When caustic soda is used to decompose the oil, *hard soap* is the result; when caustic potash is used, *soft soap* is produced.

## LESSON 51.

*Sugar* is a substance you are all familiar with, and doubtless partake of it in some form or other at every meal of the day. It occurs in every plant, but is especially abundant in the sugar-cane and sugar-beet, the mallow, and the sugar-maple; it is also found in the milk of animals. An experiment performed in Lesson 42 will tell you the composition of sugar. Strong sulphuric acid (oil of vitriol) takes away water from it, and leaves nothing but ordinary charcoal. Its composition is represented by the formula $C_{12}H_{22}O_{11}$. You must not imagine that because sugar can be split up into charcoal and water, it could by any possi*bility* be prepared from these two substances. *This has* never been done. There are several

varieties of sugar, the most important being cane-sugar, grape-sugar, and milk-sugar.

*Cane-sugar* is the sweetest kind, and is therefore more highly prized than the other kinds. It is obtained from the canes by crushing these between rollers. The juice thus obtained is

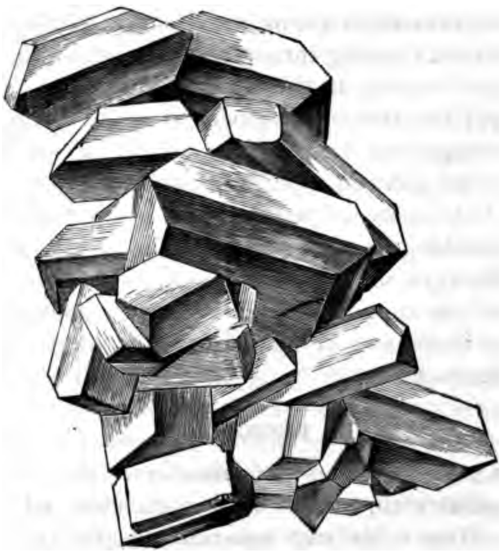

Fig. 58. CRYSTALS OF SUGAR.

mixed with a little lime, which prevents fermentation. The juice is then concentrated by boiling and evaporation until the sugar crystallises out. The dark uncrystallisable syrup remaining, known as *molasses* or treacle, is drained away. It consists largely of grape-sugar.

The raw crystals, with which you are familiar as *brown sugar*, are refined by boiling with solution of lime; then the syrup is filtered through animal charcoal, which decolourises it, and is again crystallised. When allowed to crystallise undisturbed, sugar becomes a transparent solid like glass. I daresay you have often noticed in eating sugar-candy that there is a thread running through the centre, discovered after breaking up the candy. In making sugar-candy this thread is suspended in the syrup, and the large and hard crystals collect around it as you see them in a lump of sugar-candy.

*Loaf-sugar* is composed of very small crystals; in making it the syrup is constantly stirred while crystallising.

*Grape-sugar* is found in large quantities in ripe fruits, and in small quantities in the blood of animals.

## LESSON 52.

One constituent of *wood* you are already familiar with, for we have made charcoal from it. The other two constituents are hydrogen and oxygen. Thus wood is composed of the same three elements as sugar and starch, only combined in a different way. The substance of which wood chiefly consists is *cellulose*. The whole of a plant, with the exception of the sap and colouring matters, is almost entirely cellulose. It is, therefore, as you may imagine,

one of the most important substances in the world.

All cotton and linen goods are composed almost entirely of cellulose, and paper consists of cellulose only.

Paper is usually made from rags. These are sorted, cleaned, and bleached by chloride of lime (which contains free chlorine), and are then made into a pulp with water. This pulp is spread in a thin film over hot wire or flannel strainers. When this film is dry it forms blotting-paper. To render the blotting-paper fit to carry ink on its surface, it is coated with a mixture of alum and glue called *size*.

When cellulose is heated with strong sulphuric acid it becomes *dextrin*, which is a sort of gum. If the action is continued, it finally becomes sugar. Dextrin is commonly known as *British gum;* it is used by calico-printers for mixing their colours, and for various other purposes.

*Starch*, when analysed, is found to consist of identically the same elements as cellulose, but in other respects it differs greatly from it. Some of these differences we shall learn more about later on; for the present the iodine test is quite sufficient to distinguish it. A few grains of ordinary starch are put into a glass jar full of water, then a few drops of tincture of iodine are added to the water, the mixture is stirred up, and at once a dark blue colour is produced, due to the combination of

the iodine and starch. Starch is not dissolved by cold water, but if it is boiled with water, it forms a thick paste with it, which is used for stiffening linen.

Starch is found in plants, never in animals. Three-fifths of the flour of which bread is made consists of starch ; it forms the chief part of rice and potato ; while arrowroot, sago, and tapioca are nearly pure starch.

Starch may be obtained from wheat-flour by mixing the flour into dough and washing with water on a linen cloth, kneading all the time. A milky fluid runs through the cloth, which is simply starch in suspension, and if this be allowed to stand, the starch settles to the bottom. Starch may also be made from potato, or any of the other seeds containing it, but for commercial purposes it is usually obtained from rice.

## LESSON 53.

When starch is boiled with dilute sulphuric acid it becomes first dextrin, and finally sugar.

Perhaps you have noticed how the preserved fruits your mother has made have sometimes "gone bad," and she has had to boil them over again with more sugar.

Perhaps you have also wondered how it is that "bread rises."

This is the reason. In making the dough *yeast* is mixed with it. This yeast is really a *very small* plant, so small as not to be visible

to the naked eye. In growing, this minute plant splits up the sugar which always forms part of flour into alcohol and carbonic acid gas. The carbonic acid gas swells out the dough in its efforts to escape, rendering it porous. After the dough is made sufficiently porous (or, in other words, after it has risen enough), it is put in the oven. The heat of the oven kills the yeast-plant, and at the same time expands the gas, and renders the bread still lighter and more porous. At the same time the alcohol and much of the water with which the dough was made are expelled by the heat.

Now the same yeast-plant which decomposes the sugar in dough decomposes the sugar in preserved fruits, unless the access of air is carefully prevented. Any substance containing sugar will undergo this process of *fermentation* under favourable circumstances; and so it comes to pass that wine is obtained from grapes, beer from barley, and so on. In these, as well as in all spirits, the active principle is *alcohol*. Alcohol is a colourless volatile liquid, which can be separated from beer or wine by distillation. The same apparatus will serve as we used in distilling water; alcohol becomes a vapour at a much lower temperature than water, and so if the heat of the lamp is so regulated as not to heat the beer or wine to the boiling point of water, all the alcohol can be collected by itself at the other end of the apparatus. The abuse

of alcoholic drinks is a most prolific source of disease, and even the smallest amount of alcohol is very injurious to all boys and girls.

## LESSON 54.

When wine or beer is kept exposed to the air it turns sour, and *vinegar* is formed. This is due to another form of fermentation, during which a plant grows, closely allied to that producing alcohol from sugar, but not identical with it. The formation of vinegar from alcohol occurring here is effected by oxidation—that is, by giving oxygen to the alcohol. In France wine is generally used in making vinegar; in England malt is used. The malt is first fermented, and alcohol thus produced; then by exposure of this to the air for a considerable time vinegar results.

The essential part of vinegar is an acid, called *acetic acid*, just as the essential part of wine or beer is alcohol. Vinegar, in fact, is a weak solution of acetic acid.

Fig. 59. THE LEAD TREE.

Sugar of lead is a salt produced by dissolving lead in acetic acid. It is called sugar of lead owing to its sweet taste, or more correctly acetate of lead. It is very poisonous.

*A very* pretty experiment can be made with *this salt.* Dissolve half an ounce of the sugar

of lead in a bottle containing six ounces of water, adding a little vinegar if the solution is not quite clear. Fasten in the cork a rod of zinc, as seen in fig. 59. The zinc will soon appear to have little spangles on it, and these will gradually branch in all directions, forming a sort of tree, which is made of the metal lead. The zinc takes the place of the lead in the solution, forming acetate of zinc.

Verdigris is the acetate of copper. It is a green-coloured salt used in painting, and very poisonous. Sometimes this is formed in copper cooking vessels, especially when there is any vinegar in the food. Copper vessels ought always to be lined with tin.

## LESSON 55.

You will remember that when starch was obtained by washing dough (page 156) a gummy substance was left on the linen cloth, which the water did not wash away. This is called *gluten*. Unlike all the substances we have hitherto considered, it contains nitrogen, as well as hydrogen, oxygen, and carbon. The gluten obtained from barley and other sorts of grain is more adhesive than that obtained from wheat, and so these do not make bread so light and pleasant to eat, as wheat bread is.

After the starch was washed away from the dough it settled to the bottom of the water. If we now examine this water, we shall find that it

contains in solution a substance which, on boiling the water, is coagulated—that is, thrown down from the solution. This is *albumen*, a substance practically identical with the white of egg, and containing the four elements carbon, hydrogen, oxygen, and nitrogen, with the addition of a small quantity of sulphur and phosphorus.

If we examined the water very carefully, we should find a little sugar in it ; so it is evident that wheat-flour consists of gluten, albumen, starch, and sugar.

*Milk* consists chiefly of water, oil, albumen, and caseine. The oil is in very minute particles, each of which is contained in tiny bags composed of albumen. These rise to the top as *cream* ; and *butter* is made by churning or shaking the cream until the oil or fat is set free from these tiny envelopes.

If, after the cream has been separated, milk be gently warmed and a little dilute acid or rennet be added to it, it divides into two parts : a solid part called the *curd*, which contains *caseine*, a substance closely allied to albumen ; and a liquid part called *whey*, which contains milk-sugar and other constituents of the milk dissolved in water. *Cheese* is made from the curd by subjecting it to pressure in moulds.

The poorer cheeses contain little except caseine ; these are very nourishing, but are apt to be hard and indigestible (especially if toasted). A certain amount of cream is added in making

the richer cheeses ; this makes them softer and more digestible. *Cream cheeses* are cheeses which have not been pressed so much as the ordinary ones, and are eaten fresh. All ordinary cheeses contain a certain proportion of butter; occasionally, however, cheeses are made from skim milk (deprived of its butter). Of such a cheese it has been said that "dogs bark at it, pigs grunt at it, but neither of them can bite it."

**Fats are solid, oils liquid. They all contain varying proportions of stearin, palmitin, and olein. Alkalies split them up, forming soaps and glycerine.**

**The three chief forms of sugar are cane-sugar, grape-sugar, and milk-sugar.**

**Cellulose is the main constituent of plants.**

**Starch is insoluble in water; it turns blue with iodine.**

**The growth of the yeast-plant splits up sugar into alcohol and carbonic acid. Acetic acid is formed from alcohol by another fermentation.**

**Gluten and albumen form the nitrogenous part of bread.**

**Cream forms butter. Cheese is chiefly formed of caseine.**

# CHAPTER XV.

## THE PRINCIPLES OF AGRICULTURE.

### LESSON 56.

Now that we have learnt some of the more important facts and principles in chemistry, it will be useful to look at one of the most important applications of these in the tilling of the land, or agriculture.

There are many factors concerned in the production of good crops. Rain and sunshine are *both* essential, and it is very important that

there should be a due proportion of each of these. But they are out of the personal control of the farmer.

The soil, however, and the manures with which he enriches the soil, are under his control to a large extent, as are also the seeds he sows.

Let us first consider the soil. Plants receive a large proportion of their food from the soil; it is therefore very important to know its composition. All soils are not of the same kind. There are different soils, as there are different plants; and different soils are suitable for different plants.

There are four main kinds of soil. The first kind consists mainly of sand. This is chemically known as *silica*, and is the oxide of the element silicon. Sandy soils soon dry, owing to the water draining through them rapidly. You may shake up sand in a bottle of water for as long as you like, and it will not dissolve. *Plants are only able to feed on substances that are dissolved in water;* therefore pure sand will not support the life of a plant. It is, however, seldom found pure, but mixed with one of the following kinds of soil.

*Clay* forms the second kind of soil. It is composed of a combination of the metallic oxide alumina with silica, called silicate of alumina. It also usually contains some potash, soda, lime, and iron oxide in smaller quantities, and these

are important plant foods. Clay is very adhesive, and does not allow water to run through it easily. This enables a clay soil to resist the drought of a dry summer, and to retain the water which is essential for the growth of plants. But if the weather is wet, clay is cold to plants, and makes them late to mature; also it is found that though fresh water is necessary for plants, stale water tends to make them rot. Clay soil is much more difficult to cultivate than other kinds, on account of its heaviness. It is much improved by mixing with sand, which renders the clay more porous. The addition of lime to it is also very valuable, as it liberates the soda, potash, and other bases from their combinations in the clay, leaving them free for plants to absorb. Lime also promotes the decay of vegetable matter in the soil, and so prepares nitrogen compounds for absorption by the roots, and these nitrogen compounds (chiefly ammonia and nitrates) are quite essential for plants.

## LESSON 57.

The third kind of soil consists of *limestone* chiefly. It is found in the chalk-hills which reach from Kent to Wilts and from Dorsetshire to Yorkshire. Limestone is chemically identical with chalk, and can be changed into quick-lime by the action of heat. This is actually effected in lime-kilns.

Chalk soils are light and porous. They tend to become very hot and dry, especially in dry seasons, and grass is more easily scorched on them than on other soils. It is found that they are adapted for the growth of grass and turnips, but not so suitable as clay for beans or wheat.

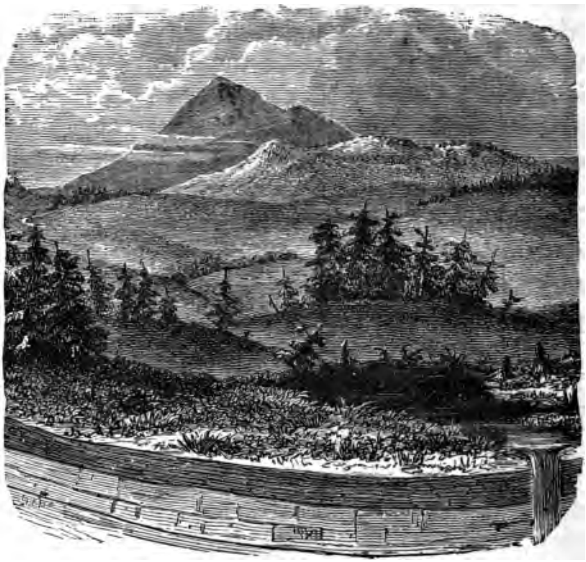

Fig. 61. A Peat-bog.

Oxides of phosphorus and iron, silica, gypsum, etc., occur with limestone, and furnish important food for plants. Lime itself is essential to the growth of plants, as it is always found in their ash.

*Humus soils* form the fourth kind. These

are so called because they contain a large amount of decayed vegetable matter, or *humus.* In some cases whole plants have decayed year after year and produced peat. In Ireland alone there are four thousand square miles covered with peat morasses (fig. 61). This decayed vegetable matter soaks up water like a sponge, instead of allowing it to penetrate downwards; and so the first step in reclaiming these tracts of lands is to drain them freely; this allows free access of air, and so promotes the decay of the vegetable matter. Then some lime ought to be added, which still further oxidises the humus. After this the peat is burnt to increase the proportion of the ash constituents, and sand or clay is added to give firmness to the soil and to increase the proportion of inorganic matter in it.

The humus formed by the decay of plants helps to feed their successors. There is a good instance of this in the clover. This has numerous very long roots, which penetrate deeply into the soil. After the clover is cut, these roots decay, and form a valuable food for the next crop that is planted on the same soil, especially if it has deep roots like clover. Now, wheat has such deep roots; so it is the general custom to sow wheat after clover, especially so as it is found that besides being fed on the humus of the clover, wheat takes just those ash constituents from the soil that the clover did not require.

Various other soils are described, which are simply mixtures of the four chief ones already named. Thus soils made up of about equal shares of sand and clay are called loams; if a soil contains much more clay than sand, it is called a *clay loam;* if more sand than clay, a *sandy loam.*

A *marl* is a clay, loam, or sandy soil of which less than a quarter consists of lime.

## LESSON 58.

All soils possess the property of being able to retain moisture to a considerable extent, but clay and humus soils retain it better than the other kinds. This property is very important, as it prevents plants from withering when there is no rainfall.

Another important property possessed by soils may be studied by taking two barrels with holes in their bottom, and filling one with sand and the other with powdered clay. Next take some of the bad-smelling water that runs from a manure heap, and pour it in at the top of each barrel. The part poured into the sand comes through first, and is not so dark-coloured as when it entered. The part poured into the clay comes out later on, and is quite clear and without smell. It has been deprived of all the materials that were dissolved in it.

This is a very important property of soils,

especially clay soils. They retain the dissolved food, even while they allow the water to run through. If it were not for this retaining power of the soil, the manures with which soils are supplied would get washed away before plants have time to absorb them.

You know that the oil in a lamp rises up the cotton wick until it reaches the top, and as fast as it is burnt there, more oil rises to take its place. This is owing to the force known as capillary attraction. The intervals between the individual grains of which soils are composed being very minute, they furnish an instance of the action of this same force, and so moisture tends to spread in all directions. Not only does it sink from the surface, but in dry weather may rise from below, and it may likewise spread on all sides. In this way plants are often supplied with the water they require, when we may be inclined to wonder how it is they are not withered from the lack of rain.

We have already stated that only that part of the soil which can be dissolved in water is serviceable as a food for the plant. Silica, it is true, manages to get dissolved in small quantities, although it is insoluble in water; and it is possible that some secretion is given out by the minute root-fibres, rendering it soluble. Chalk, again, is insoluble in pure water, but rain-water always contains some carbonic acid in solution, and thus is enabled to dissolve a small amount

of chalk. Only a very small amount of even a good soil is soluble in water.

To learn what a plant requires from the soil, we must refer to what we have already learnt concerning the composition of a plant. The greater part of a plant consists of compounds containing hydrogen, oxygen, carbon, and nitrogen, which disappear when the plant is burnt; a small proportion known as the *ash*, generally about three per cent., remains behind. The ash consists of varying proportions of the bases potash, soda, magnesia, lime, iron oxide, alumina, united with chlorine, silica, carbonic, sulphuric, or phosphoric acids.

Carbon is obtained from the air, hydrogen and oxygen from water. The ash is entirely obtained from the soil. Nitrogen cannot be obtained from the abundant free nitrogen in the air, but must be in the form of a compound. This is furnished by ammonia and nitrates, which are abundantly supplied by the decay of animal or vegetable matters.

## LESSON 59.

Now that we have learnt the composition of the soil, and what the plant requires from it, you will begin to understand how the farmer may add any special substance that is deficient. Here comes in the use of manures.

It is found by experience that nitrogen (in a compound form), phosphates, and potash are the

substances that the soil chiefly requires to have added to it in order to keep it fertile. Lime also is a valuable addition, acting partly as a food, but also largely by setting free potash from the clay compounds and ammonia from humus.

Plants abstract the fertile part of the soil and build it up into their constitution. You will understand that if the farm is a grazing one, sheep or cows living on it will return a large proportion of the food they take from the soil in the shape of manure. But if corn or other seeds are grown, which require a large amount of phosphates, they are generally sold, and so not returned to the soil of the farm in the shape of manure. Milk, again, and animals that are killed for meat, carry away a large amount of phosphates from the soil, and so tend to impoverish it.

Hence the importance of manures containing phosphates. Farmyard manure is a good general manure, supplying all the kinds of food required by plants from the soil.

Peruvian guano, which consists of the dried dung of sea birds, is very rich in nitrogen and phosphates.

Where phosphates are required, bones, which consist chiefly of phosphate of lime, form a capital manure. They are generally ground to form *bone-meal*, and may be rendered more *quickly* soluble in water by previously treating with sulphuric acid.

## LESSON 60.

The farm crops usually grown may be divided into three classes—namely, grasses, legumes, and roots.

It is found that the ash of grasses contains a large amount of silica, potash and phosphates coming next in amount; lime and potash are about equal in amount in legumes, phosphates coming next; while potash is the most abundant constituent of the ash of roots, lime and phosphates taking the second and third place. From this we shall be able to judge the most suitable manure in each case. Grasses are either *cereals*—that is, grain producers, like wheat, barley, and oats—or *fodder-grasses*, like the ordinary meadow grass. Legumes, that is plants producing pods, are either grown for their seeds, like peas and beans, or for fodder, like clover, vetch, and sainfoin.

Fig. 62. Cereals.

The main roots are turnips, carrots, parsnips, mangels, and potatoes (which last are really tubers).

The land best adapted for growing wheat is a fertile clay, or clay loam. Barley is best grown on light soils, containing much limestone

when required for malting. The reason of this is that on such a soil more starch and less nitrogenous matter is produced than on a clay loam; and it is starch which changes into sugar, afterwards to become the alcohol of beer.

The oat is one of the hardiest plants that are cultivated. It will flourish anywhere, but especially in a well-drained fertile clay.

Clover is a very nutritious cattle food, and also wonderfully improves the soil for the growth of corn afterwards. It flourishes best in a deep light soil containing much lime. All legumes absorb a large amount of nitrogenous matter from the soil, as well as ammonia from the air, and yet far more nitrogen is left in the roots and stubble of the clover than can be used up by the wheat crop following.

In accordance with the facts and principles already stated, it is usual to follow one crop with another in a definite rotation. By the *rotation of crops* is meant the order in which a series of crops are made to follow each other on the same ground. Some crops draw from the soil certain ash constituents chiefly, while other crops do not require much of these, but more of other ash constituents. By growing cereals alternately with legumes and roots, time is given for the soil to recover what it has lost each year; and this return of the soil to its *healthy* unimpoverished condition is especially *likely* to occur if it is allowed to lie fallow

in the fourth year—that is, left without any crop growing on it.

In the case of the clover we have seen that a supply of decaying matter is laid up for the succeeding wheat crop. And so one crop prepares the way for another.

A good rotation is also a great convenience to the farmer, and diminishes his risks. He has various crops on different parts of his farm, and each part is varied as the years succeed each other. So if his hay is spoilt by rain, the early growth of his turnips will be favoured.

Different crops require attending to at various times of the year, and so the work of the farm is more evenly spread over every part of the year.

**Soils are composed of sand, clay, chalk, or humus, or a mixture of these. Clay and humus retain moisture best.**

**Humus soils are formed from decayed vegetables.**

**All soils have the power of retaining some moisture and of filtering nourishment from water.**

**Only substances soluble in water can supply a plant with food.**

**The main foods obtained by the**

roots are nitrates and phosphates, potash, soda, etc.

Bone supplies a good phosphate manure.

Farm crops are grasses, legumes, or roots.

Grasses are cereals or fodder-grasses.

The rotation of crops is economical, and by means of it larger crops can be obtained.

## LIST OF THE MOST DIFFICULT WORDS OCCURRING IN THIS BOOK.

NOTE.—*The meanings here given explain the words as they are used in the text only. It is intended that the scholar should commit this list to memory.*

**abolished,** done away with.
**absorbed,** sucked in.
**abstract,** take away.
**access,** entrance.
**accumulate,** collect.
**accurately,** exactly and carefully.
**adhesive,** sticky.
**agriculture,** the tillage of the land, farming.
**albumen,** the white part of an egg, and any substance similar in constitution to it.
**alkali** (see page 107).
**analysis,** separating a compound body into its component parts.
**annihilated,** done away with entirely.
**apparatus,** instruments, tools.
**apparent,** seeming.
**atmosphere,** the air which surrounds the earth.
**barometer,** an instrument which shows the pressure of the air.
**bibulous,** drinking in, spongy.
**bleach,** make white.
**botany,** the knowledge of plants.

**buoyancy,** power of floating.
**caustic,** burning.
**cellulose,** the cell-like substance of which plants are mainly formed.
**centigrade thermometer,** a form of the instrument in which the temperature between freezing point and boiling point is divided into 100 degrees.
**cereals,** the grains, such as wheat and barley, which are used for food.
**characteristic,** peculiar, distinguishing.
**circulation,** flow from one part to another.
**cohesion,** sticking together.
**colloids,** glue-like substances.
**combustible,** able to burn.
**compensating,** making up for.
**complex,** puzzling, not simple.
**composite,** made up of different parts.
**concave,** hollowed out.
**condensed,** changed from a vapour into a liquid.
**conduction,** the passage of heat from one particle to another.
**conservation of energy** (see page 51).
**constituent,** making up.
**contaminated,** spoiled, poisoned.
**convex,** rounded, bulging out.
**corresponded,** suited, fitted.
**crystallisation,** the act of forming crystals.
**crystalloids,** substances such as sugar, alum, etc., which crystallize.
**cube,** a solid square, like dice.
**cylindrical,** round, roller-like.
**decolourises,** takes away the colour.
**deflecting,** turning aside.
**depicted,** figured, drawn.
**detonates,** explodes.
**development,** growth, formation.
**diffusible,** able to diffuse, or pass through.
**diluting,** making weaker.
**diminished,** lessened.
**disc,** a plate of wood or other material round like a penny.
**dispersed,** scattered, separated.
**dissipated,** scattered, wasted.
**distillation** (see Lesson 40).
**diverge,** to turn apart.
**economy,** saving.
**element,** matter which cannot be further split up (see page 90).
**emerging,** coming out from.
**envelope,** a coating.
**equation,** a statement that two quantities are equal.
**equivalent,** equal in value to.
**erect,** upright.
**essential,** necessary, most important.
**ether,** a very light inflammable fluid.
**examine,** look into.
**exhaust,** to draw out, to empty.
**expelled,** driven out.
**factor,** something which has to be taken into account.
**focus,** the point at which rays of light converge.
**friction,** a rubbing.
**fulcrum,** a prop, or resting point.
**functions,** doings, performances.
**generator,** producer, maker.
**gigantic,** giant-like, very large.
**glair,** the clear part of an egg.
**globule,** a little ball.
**gradually,** little by little.
**hydraulic,** worked by water.
**identical,** exactly the same as.
**incompressible,** unable to be pressed into smaller bulk.
**indestructible,** unable to be destroyed.
**inflammable,** able to burn.
**injurious,** hurtful.
**insoluble,** not able to be dissolved.
**intensity,** vigour.
**interchangeable,** changing from one state to another.
**interposed,** placed between.
**inverted,** turned upside down.
**invisible,** not seen.
**landscape,** aspect of a country.
**latent,** hidden.
**legumes,** plants which produce pods, such as peas and beans.
**lens** (for meaning see page 66).
**luminous,** shining.

**maintained,** kept up.
**malt,** prepared grain used in making beer, etc.
**mariners,** sailors.
**mechanical mixture** (see page 93).
**microscope,** an instrument for magnifying small objects.
**misnomer,** a wrong name.
**modified,** altered.
**molecule** (see page 151).
**morasses,** bogs, marshy districts.
**neutralize,** counteract.
**normal,** usual, regular.
**nutritious,** nourishing.
**obliquity,** slant.
**obscure,** not clear.
**organic,** formed by animal or vegetable life.
**orifice,** a hole, or opening.
**originally,** at first.
**osmosis,** the property which enables liquids to pass through membranes.
**oxide,** the compound formed by the union of oxygen with any other element.
**parallel,** side by side.
**peculiar,** strange, odd.
**penetrate,** go into.
**permanent,** lasting.
**phenomenon,** pl. **phenomena,** any wonderful appearance.
**pneumatic trough,** a vessel used in collecting gases (see figs. 42 and 47).
**porous,** full of holes.
**practically,** to all intents and purposes.
**prism,** a wedge-shaped piece of glass.
**prolific,** fruitful.
**pungent,** sharp.
**radiation,** sending out rays in all directions, like the spokes of a wheel.
**reflected,** bent back, turned aside.
**refraction,** a turning or bending.
**repulsion,** a pushing away from each other.
**reservoir,** a place in which water is collected.
**residue,** what is left.
**rotation,** order.
**rowlocks,** the places in which the oars work at the side of a boat.
**satellite,** a small body which revolves round a larger body, like the moon revolves round the earth.
**sensible,** able to be perceived by the senses.
**solution,** a liquid in which something has been dissolved.
**specific gravity,** the weight of a substance compared with that of an equal bulk of water.
**speculate,** to look into, to consider.
**spontaneously,** of its own accord.
**stable,** lasting.
**stagnant,** still, not flowing.
**submarine,** under the sea.
**suffocated,** stifled, choked.
**suspended,** hung up.
**symptoms,** signs.
**synthesis,** putting together elementary bodies to form a compound.
**tannin,** a bitter substance obtained from bark used in tanning.
**temporary,** only lasting for a time.
**tenacious,** holding or sticking together.
**tendency,** inclination.
**theoretical,** thought out in one's mind, not put into practice.
**thermometer,** an instrument for measuring heat.
**tincture,** the mixture obtained by dissolving a substance in spirits of wine.
**transformation,** change.
**transparent,** clear, able to be seen through.
**ultimate,** last.
**uniform,** same all through.
**unimpoverished,** rich, not made poor.
**universe,** the world and all created things.
**utilised,** made use of.
**vacuum,** an entirely empty space.
**ventilation,** supply of fresh air.
**vertically,** straight downwards.
**vital,** affecting life or death.
**volatile,** apt to evaporate, or change into vapour.